

Description

EXPRESSION OF PROTEIN C

Technical Field

5 The present invention relates generally to plasma proteins and DNA sequences encoding them, and more specifically, to the expression of proteins having substantially the same structure and/or activity as human protein C or human activated protein C.

Background Art

10 Protein C is a zymogen, or precursor, of a serine protease which plays an important role in the regulation of blood coagulation and generation of fibrinolytic activity *in vivo*. It is synthesized in the liver as a single-chain polypeptide which undergoes considerable processing to give rise to a two-chain molecule comprising heavy (Mr = 40,000) and light (Mr = 21,000) chains held together by a disulfide bond. The circulating two-chain intermediate is converted to the biologically active form of the molecule, known as "activated protein C" (APC),
 15 by the thrombin-mediated cleavage of a 12-residue peptide from the aminoterminal of the heavy chain. The cleavage reaction is augmented *in vivo* by thrombomodulin, an endothelial cell cofactor (Esmon and Owen, *Proc. Natl. Acad. Sci. USA* 78: 2249-2252, 1981).

Protein C is a vitamin K-dependent glycoprotein which contains approximately nine residues of gamma-carboxyglutamic acid (Gla) and one equivalent of beta-hydroxyaspartic acid which are formed by
 20 post-translational modifications of glutamic acid and aspartic acid residues, respectively. The post-translational formation of specific gamma-carboxyglutamic acid residues in protein C requires vitamin K. These unusual amino acid residues bind to calcium ions and are believed to be responsible for the interaction of the protein with phospholipid, which is required for the biological activity of protein C.

In contrast to the coagulation-promoting action of other vitamin K-dependent plasma proteins, such as
 25 factor VII, factor IX, and factor X, activated protein C acts as a regulator of the coagulation process through the inactivation of factor Va and factor VIIIa by limited proteolysis. The inactivation of factors Va and VIIIa by protein C is dependent upon the presence of acidic phospholipids and calcium ions. Protein S has been reported to regulate this activity by accelerating the APC-catalyzed proteolysis of factor Va (Walker, *J. Biol. Chem.* 255:
 5521-5524, 1980).

Protein C has also been implicated in the action of tissue-type plasminogen activator (Kisiel and Fujikawa,
 30 *Behring Inst. Mitt.* 73: 29-42, 1983). Infusion of bovine APC into dogs results in increased plasminogen activator activity (Comp and Esmon, *J. Clin. Invest.* 68: 1221-1228, 1981). Recent studies (Sakata et al., *Proc. Natl. Acad. Sci. USA* 82: 1121-1125, 1985) have shown that addition of APC to cultured endothelial cells leads to a rapid,
 35 dose-dependent increase in fibrinolytic activity in the conditioned media, reflecting increases in the activity of both urokinase-related and tissue-type plasminogen activators by the cells. APC treatment also results in a dose-dependent decrease in antiactivator activity.

Protein C deficiency is associated with recurrent thrombotic disease (Broekmans et al., *New Eng. J. Med.*
 309: 340-344, 1983; and Seligsohn et al., *New Eng. J. Med.* 310: 559-562, 1984) and may result from genetic disorder or from trauma, such as liver disease or surgery. This condition is generally treated with oral
 40 anticoagulants. Beneficial effects have also been obtained through the infusion of protein C-containing normal plasma (see Gardiner and Griffin in *Prog. in Hematology*, ed. Brown, Grune & Stratton, NY, 13: 265-278). In addition, some investigators have discovered that the anti-coagulant activity of protein C is useful in treating thrombotic disorders, such as venous thrombosis (Smith et al., PCT Publication No. WO 85/00521). In some parts of the world, it is estimated that approximately 1 in 16,000 individuals exhibit protein C deficiency. Further,
 45 a total deficiency in protein C is fatal in newborns.

Finally, exogenous protein C has been shown to prevent the coagulopathic and lethal effects of gram
 negative septicemia (Taylor et al., *J. Clin. Invest.* 79: 918-925, 1987). Data obtained from studies with baboons suggest that protein C plays a natural role in protecting against septicemia.

While natural protein C may be purified from clotting factor concentrates (Marlar et al., *Blood* 59: 1067-1072)
 50 or from plasma (Kisiel, *ibid.*), it is a complex and expensive process, in part due to the limited availability of the starting material and the low concentration of protein C in plasma. Furthermore, the therapeutic use of products derived from human blood carries the risk of disease transmission by, for example, hepatitis virus, cytomegalovirus, or the causative agent of acquired immune deficiency syndrome (AIDS). In view of protein C's clinical applicability in the treatment of thrombotic disorders, the production of useful quantities of protein
 55 C and activated protein C is clearly invaluable.

Disclosure of the Invention

Briefly stated, the present invention discloses DNA sequences which code for proteins having substantially
 60 the same structure and/or biological activity as human protein C or human activated protein C. In one aspect of the present invention, the DNA sequence further codes for the amino acid sequence (R₁)_n-R₂-R₃-R₄, wherein R₁, R₂, R₃ and R₄ are Lys or Arg and n = 0, 1, 2, or 3, at the cleavage site of the light and heavy chains. In a preferred embodiment, the amino acid sequence at the cleavage site is Arg-Arg-Lys-Arg. In another aspect of the present invention, the protein includes the substitution of residue 158 (Asp) with a non-acidic amino acid

residue such as Ala, Ser, Thr or Gly. In a related aspect, the protein includes the substitution of residue 154 (His) with a basic amino acid residue such as Lys or Arg. In another aspect, the protein includes the substitution of the Lys-Arg at residues 156-157 of native protein C with Lys-Lys or Arg-Arg.

Yet another aspect of the present invention is directed toward a DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, the sequence further encoding the pre-pro peptide of a protein such as factor VII, factor IX, factor X, prothrombin or protein S.

In addition, the present invention discloses expression vectors capable of integration in mammalian host cell DNA, including a promoter followed downstream by a DNA sequence which encodes a protein having substantially the same structure and/or activity as human protein C or human activated protein C as set forth above, transcription of the nucleotide sequence being directed by the promoter. The nucleotide sequence is followed downstream by a polyadenylation signal. In one embodiment, the expression vector includes a selectable marker located between the nucleotide sequence and the polyadenylation signal, transcription of the selectable marker being directed by the promoter. The expression vector may also include a set of RNA splice sites.

A related aspect of the present invention discloses mammalian cells transfected to express a protein which, upon activation, has substantially the same biological activity as human activated protein C. The mammalian cells are transfected with an expression vector capable of integration in mammalian host cell DNA, the expression vector including a promoter followed downstream by a DNA sequence as described above. Within one embodiment, a selectable marker is also introduced into the cells and stably transfected cells are selected. Mammalian cells transfected to express a protein which has substantially the same biological activity as human activated protein C are also disclosed. Preferred host cells for use within the present invention are COS, BHK and 293 cells.

A further aspect of the invention discloses a method for producing a protein which, upon activation, has substantially the same biological activity as human activated protein C. The method comprises (a) introducing into a mammalian host cell an expression vector comprising a DNA sequence as described above, which encodes a protein having substantially the same structure and/or activity as human protein C; (b) growing said mammalian host cell in an appropriate medium; and (c) isolating the protein product encoded by said DNA sequence and produced by said mammalian host cell. The protein product produced according to this method is also disclosed. A method for producing a protein which has substantially the same structure and/or biological activity as human activated protein C is also disclosed.

The proteins described within the present invention may be used as active therapeutic substances, including use in the regulation of blood coagulation. Further, these proteins may be combined with a physiologically acceptable carrier and/or diluent to provide suitable pharmaceutical compositions.

Other aspects of the invention will become evident upon reference to the detailed description and attached drawings.

Brief Description of the Drawings

Figure 1 is a partial restriction map of the protein C cDNA in pHCλ6L. The coding region is indicated by an open box.

Figure 2 illustrates the nucleotide sequence of the complete protein C cDNA and the deduced amino acid sequence of protein C. Arrows indicate cleavage sites for removal of the connecting dipeptide and activation peptide.

Figure 3 illustrates a restriction enzyme map of the genomic DNA coding for human protein C. Numbers below the line indicate length in kilobases (kb).

Figure 4 illustrates the complete genomic sequence, including exons and introns, of the human protein C gene. Arrowheads indicate intron-exon splice junctions. The polyadenylation or processing sequences of A-T-T-A-A-A and A-A-T-A-A-A at the 3' end are boxed. ♦, potential carbohydrate attachment sites; /, apparent cleavage sites for processing of the connecting dipeptide; ↓, site of cleavage in the heavy chain when protein C is converted to activated protein C; ●, sites of polyadenylation.

Figure 5 illustrates a schematic two-dimensional model for the structure of human protein C.

Figure 6 illustrates the subcloning of the 5' and 3' portions of a protein C partial cDNA clone.

Figure 7 illustrates the removal of intron A from the genomic clone, resulting in the fusion of exons I and II.

Figure 8 illustrates the fusion of exons I and II to the 5'-most portion of the cDNA insert of figure 1.

Figure 9 illustrates the construction of a plasmid comprising the complete coding sequence for protein C.

Figure 10 illustrates the expression vector pD7C. Symbols used are ori, the adenovirus 5 0-I map unit sequence; E, the SV40 enhancer; Ad2MLP, the adenovirus 2 major late promoter; LI-3, the adenovirus 2 tripartite leader; 5'ss, 5' splice site; 3'ss, 3' splice site; pA, the SV40 early polyadenylation signal; and Δ, the deleted region of the pBR322 "poison" sequences.

Figure 11 illustrates the expression vector pD5(PC-DHFR). DHFR denotes the methotrexate resistant mutant dihydrofolate reductase gene sequence; pA denotes the SV40 late polyadenylation signal. Other symbols used are as described for Figure 10.

Figure 12 illustrates the expression vector pDX/PC. Symbols used are as described for Figure 11.

Figure 13 illustrates the results of an assay for activated protein C on media samples from transfected 293 cells.

Figure 14 illustrates the expression vectors pDX/PC962 and PC962/229.

Figure 15 illustrates the anticoagulant activity of protein C prepared according to certain embodiments of the present invention.

Best Mode for Carrying Out the Invention

Prior to setting forth the invention, it may be helpful to an understanding thereof to set forth definitions of certain terms to be used hereinafter.

Biological Activity:

A function or set of functions performed by a molecule in a biological context (i.e., in an organism or an *in vitro* facsimile). Biological activities of proteins may be divided into catalytic and effector activities. Catalytic activities of the vitamin K-dependent plasma proteins generally involve the specific proteolytic cleavage of other plasma proteins, resulting in activation or deactivation of the substrate. Effector activities include specific binding of the biologically active molecule to calcium, phospholipids or other small molecules, to macromolecules, such as proteins, or to cells. Effector activity frequently augments, or is essential to, catalytic activity under physiological conditions.

For protein C, biological activity is characterized by its anticoagulant and fibrinolytic properties. Protein C, when activated, inactivates factor Va and factor VIIIa in the presence of phospholipid and calcium. Protein S appears to be involved in the regulation of this function (Walker, *ibid.*). Activated protein C also enhances fibrinolysis, an effect believed to be mediated by the lowering of levels of plasminogen activator inhibitors (van Hinsbergh et al., *Blood* 65: 444-451, 1985). As more fully described below, that portion of protein C encoded by exons VII and VIII of the protein C gene is primarily responsible for its catalytic activities.

Pre-Pro Peptide:

An amino acid sequence which occurs at the amino terminus of some proteins and is generally cleaved from the protein during translocation. Pre-pro peptides comprise sequences directing the protein into the secretion pathway of the cell (signal sequences) and are characterized by the presence of a core of hydrophobic amino acids. They may also comprise processing signals. As used herein, the term "pre-pro peptide" may also mean a portion of a naturally occurring pre-pro peptide.

Expression Unit:

A DNA construct comprising a primary nucleotide sequence encoding a protein of interest, together with other nucleotide sequences which direct and control the transcription of the primary nucleotide sequence. An expression unit consists of at least the primary nucleotide sequence and a promoter sequence located upstream from and operably linked to the primary nucleotide sequence and a polyadenylation signal located downstream. Additional genetic elements may also be included to enhance efficiency of expression. These elements include enhancer sequences, leaders, and mRNA splice sites.

Expression Vector:

A DNA molecule which contains, *inter alia*, a DNA sequence encoding a protein of interest together with a promoter and other sequences which facilitate expression of the protein. Expression vectors further contain genetic information which provides for their replication in a host cell, either by autonomous replication or by integration into the host genome. Examples of expression vectors commonly used for recombinant DNA are plasmids and certain viruses, although they may contain elements of both. They also may include a selectable marker.

As noted above, protein C is produced in the liver and requires vitamin K for its biosynthesis. Vitamin K is necessary for the formation of specific gamma-carboxyglutamic acid residues in the amino-terminal region of the light chain. These amino acid residues are formed by a post-translational modification, and are required for calcium-mediated binding to phospholipid. In addition, protein C contains one beta-hydroxyaspartic acid residue which is also formed in a post-translational modification. However, the role of this amino acid residue is not known.

Given the fact that the activity of protein C is dependent upon post-translational modifications involving the gamma carboxylation of specific glutamic acid residues and cleavage to the two-chain form, and may also be dependent upon the hydroxylation of a specific aspartic acid residue, it is unlikely that an active product could be produced through the cloning and expression of protein C in a microorganism.

Accordingly, the present invention provides a method of producing a protein which is gamma-carboxylated and, upon activation, has the biological activity of human activated protein C through the use of mammalian cells transfected to stably express the protein.

The present invention further provides a method for producing a protein which is gamma-carboxylated and has the biological activity of human activated protein C without the necessity for activation.

The light and heavy chains of bovine protein C have been sequenced (Ferlund and Stenflo, *J. Biol. Chem.* 257: 12170-12179, 1982; and Stenflo and Ferlund, *J. Biol. Chem.* 257: 12180-12190, 1982). Isolation and characterization of human protein C have been described by Kisiel, *J. Clin. Invest.* 64: 761-769, 1979. The

anticoagulant activities of both the human and bovine enzymes were found to be highly species specific. Species specificity is believed to be mediated by protein S (Walker, *Thromb. Res.* 22: 321-327, 1981). However, the human and bovine proteins show considerable overall structural homology to each other and to other vitamin K-dependent plasma proteins, including prothrombin, factor VII, factor IX, and factor X. Similarities include the presence of the Gla residues in the light chain and the active site serine in the heavy chain, as well as other amino acid sequence homology in the amino-terminal region of the light chain.

Within the present invention, a λ gt11 cDNA library was prepared from human liver mRNA. This library was then screened with 125 I-labeled antibody to human protein C. Antibody-reactive clones were further analyzed for the synthesis of a fusion protein of β -galactosidase and protein C in the λ gt11 vector.

One of the clones gave a strong signal with the antibody probe and was found to contain an insert of approximately 1400 bp. DNA sequence analysis of the DNA insert revealed a predicted amino acid sequence which shows a high degree of homology to major portions of bovine protein C, as determined by Fernlund and Stenflo (*J. Biol. Chem.* 257: 12170-12179; *J. Biol. Chem.* 257: 12180-12190).

The DNA insert contained the majority of the coding region for protein C beginning with amino acid 64 of the light chain, including the entire heavy chain coding region, and proceeding to the termination codon. Further, following the stop codon of the heavy chain, there were 294 base pairs of 3' noncoding sequence and a poly (A) tail of 9 base pairs. The processing or polyadenylation signal A-A-T-A-A was present 13 base pairs upstream from the poly (A) tail in this cDNA insert. This sequence was one 30 of two potential polyadenylation sites.

The cDNA sequence also encodes the dipeptide Lys-Arg at position 156-157 (numbering of amino acids is shown in Figure 2), which separates the light chain from the heavy chain and is removed during processing by proteolytic cleavage resulting in secretion of the two-chain molecule. Upon activation of the two-chain molecule by thrombin, the heavy chain of human protein C is cleaved between arginine-169 and leucine-170, releasing the activation peptide (Figure 2).

By a similar method, a second cDNA which lacked the coding sequence for the pre-pro peptide and the first 23 amino acids of protein C was isolated. Using this cDNA as a hybridization probe, the remainder of the coding sequence was obtained from a human genomic DNA library in λ Charon 4A (Foster et al., *Proc. Natl. Acad. Sci. USA* 82: 4673-4677, 1985). Three different λ Charon 4A phage were isolated that contained overlapping inserts for the protein C gene.

The positions of exons on the three phage clones were determined by Southern blot hybridization of digests of these clones with probes made from the 1400 bp cDNA described above. The genomic DNA inserts in these clones were mapped by single and double restriction enzyme digestion followed by agarose gel electrophoresis, Southern blotting, and hybridization to radiolabeled 5' and 3' probes derived from the cDNA for human protein C, as shown in Figure 3.

DNA sequencing studies were performed using the dideoxy chain-termination method. As shown in Figure 4, the nucleotide sequence for the gene for human protein C spans approximately 11 kb of DNA. These studies further revealed a potential pre-pro peptide of 42 amino acids. The pre-pro sequence is cleaved by a signal peptidase following the Gly residue at position -25. Processing to the mature protein involves additional proteolytic cleavage following residue -1 to remove the amino-terminal propeptide, and at residues 155 and 157 to remove the Lys-Arg dipeptide which connects the light and heavy chains. This final processing yields a light chain of 155 amino acids and a heavy chain of 262 amino acids.

The protein C gene is composed of eight exons ranging in size from 25 to 885 nucleotides, and seven introns ranging in size from 92 to 2668 nucleotides. Exon I and a portion of exon II code for the 42 amino acid pre-pro peptide. The remaining portion of exon II, exon III, exon IV, exon V, and a portion of exon VI code for the light chain of protein C. The remaining portion of exon VI, exon VII, and exon VIII code for the heavy chain of protein C. The amino acid and DNA sequences for a cDNA coding for human protein C are shown in Figure 2.

The introns in the gene for protein C are located primarily between various functional domains. Exon II spans the highly conserved region of the pre-pro peptide and the gamma-carboxyglutamic acid (Gla) domain. Exon III includes a stretch of eight amino acids which connect the Gla and growth factor domains. Exons IV and V each represent a potential growth factor domain, while exon VI covers a connecting region which includes the activation peptide. Exons VII and VIII cover the catalytic domain typical of all serine proteases.

The amino acid sequence and proposed structure for human pre-pro protein C are shown in Figure 5. Protein C is shown without the Lys-Arg dipeptide, which connects the light and heavy chains. The location of the seven introns (A through G) is indicated by solid bars. Amino acids flanking known proteolytic cleavage sites are circled.

designates potential carbohydrate binding sites. The first amino acid in the light chain, activation peptide, and heavy chain start with number 1. This numbering differs from that shown in Figures 2 and 4.

Carbohydrate attachment sites are located at residue 97 in the light chain and residues 79, 144, and 160 in the heavy chain, according to the numbering scheme of Figure 5. The carbohydrate moiety is covalently linked to Asn. In the majority of instances, the carbohydrate attachment environment can be represented by Asn-X-Ser or Asn-X-Thr, where X = any amino acid.

As noted above, protein C plays a regulatory role in the coagulation process. The catalytic domain, encoded by exons VII and VIII, possesses serine protease activity which specifically cleaves certain plasma proteins (i.e., factors Va and VIIIa), resulting in their deactivation. As a result of this selective proteolysis, protein C displays anticoagulant and fibrinolytic activities.

Due to the presence of intervening sequences in the genomic clone, merely joining the genomic and cDNA sequences to provide a complete coding sequence is not sufficient for constructing an acceptable expression unit. It is therefore necessary to delete these intervening sequences for reasons more fully described below if a genomic clone is used to construct the expression unit.

The 5' coding region may also be obtained by alternative methods and consequently eliminate the need to delete intervening sequences. The 5' coding region may be obtained by using probes derived from the existing cDNA or genomic clones to probe additional libraries. By this method, a full-length cDNA was isolated. Furthermore, the amino-terminal portions of the vitamin K-dependent plasma proteins are responsible for their respective calcium binding activities. It has been found that, as a result of this functional homology, the calcium binding domains of these molecules may be interchanged and still retain the activity specific to the catalytic domain of the resultant molecule. For example, as described in U.S. Patent Application Serial No. 724,311, filed April 17, 1985, and published as European Patent Office publication 200,421, the amino-terminal portion (calcium binding domain) of factor IX may be joined to factor VII at amino acid 38 to produce a protein having the activity of factor VII. Factor VII, factor IX, factor X, prothrombin, and protein S share this amino-terminal sequence homology with protein C. Consequently, a cloned sequence comprising the 5'-coding region of the gene for any of these proteins might be substituted for the corresponding sequence of the protein C gene. Additionally, suitable coding sequences may be synthesized based on the known amino acid sequences of several of the vitamin K-dependent plasma proteins or on the sequence of protein C disclosed herein. Techniques for producing synthetic nucleotide sequences are well known in the art. For example, a set of overlapping oligonucleotides may be synthesized and annealed in pairs to yield double-stranded fragments with overlapping cohesive termini. These fragments are then ligated as any restriction fragments would be. The resultant synthetic fragment is then ligated to the cDNA at a convenient restriction site. The junction sequence may be modified as necessary by oligonucleotide-directed mutagenesis.

When clones representing the entire coding sequence have been obtained, the appropriate regions may be joined, as necessary, to generate the desired coding sequence. Fragments obtained from one or more libraries are cut with appropriate restriction endonucleases and joined together enzymatically in the proper orientation. Depending on the fragments and the particular restriction endonucleases chosen, it may be necessary to remove unwanted DNA sequences through a "loop out" process of deletion mutagenesis or through a combination of restriction endonuclease cleavage and mutagenesis. The sequence so obtained should preferably be in the form of a continuous open reading frame, that is, that it lack the intervening sequences (introns) generally found on higher eukaryotic genes. The presence of introns in cloned genes may lead to aberrant splicing of messenger RNA and/or reduced efficiency of gene expression or instability upon amplification when the gene sequence is introduced into a mammalian host cell. It is preferred that this coding sequence further encode a pre-pro peptide in order to facilitate proper processing and secretion of the protein C produced according to the present invention. The pre-pro peptide may be that of protein C or another secreted protein, such as factor IX, factor VII, or prothrombin.

Under some circumstances, it may be desirable to produce activated protein C directly, thereby removing the need to activate the protein product either *in vitro* or *in vivo*. The cleavage sites involved in the maturation and activation of protein C are known (Foster and Davie, *ibid.*). A sequence encoding APC may be constructed by deleting the region encoding the activation peptide through oligonucleotide-directed deletion mutagenesis. The resultant protein will then become activated by removal of the Lys-Arg dipeptide during normal proteolytic processing in the secretion pathway of the host cell. It has been found that proteins lacking the activation peptide are nevertheless properly processed by the host cells, resulting in secretion of activated protein C.

In order to enhance the proteolytic processing involved in the maturation of the recombinant protein C to the two-chain form, it may be desirable to modify the amino acid sequence around the processing site. Such modification has been found to facilitate the proper processing of recombinant protein C in transfected cells.

Efficient cleavage may increase the specific activity of the protein, given that single-chain protein C is not known to be activated in the bloodstream. As previously noted, this maturation process involves the removal of the dipeptide Lys-Arg (amino acids 156-157) (Foster and Davie, *Proc. Natl. Acad. Sci. USA* 81: 4766-4770, 1984). Modifications to the amino acid sequence in the vicinity of this processing site include the substitution and/or insertion of amino acids. One such group of modifications is the alteration of the amino acid sequence to include the sequence $(R_1)_n-R_2-R_3-R_4$, wherein R_1 , R_2 , R_3 and R_4 are Lys or Arg and $n=0, 1, 2$ or 3 , in place of the native Lys-Arg dipeptide. A particularly preferred modification of this group is the sequence Arg-Arg-Lys-Arg. This sequence has been found to enhance processing of recombinant protein C by about five-fold in transfected BHK cells. A second group of modifications includes the substitution of amino acid residue 154 (His) of native protein C with a basic amino acid residue (i.e., Lys or Arg) to give a processing site sequence of the general formula $R_1-X-R_2-R_3$, wherein R_1 , R_2 , and R_3 are Lys or Arg, and X is an amino acid other than Lys or Arg, preferably Leu. A third group of modifications includes substitution of the Asp residue at position 158 with a non-acidic amino acid residue. Use of a small neutral amino acid, such as Ala, Ser, Thr or Gly is preferred. A fourth group of modifications includes the substitution of Lys-Lys or Arg-Arg for the Lys-Arg of native protein C. Combinations of these groups of modifications may also be made. For example, amino acid 158 may be substituted in a protein C molecule containing a processing site having the sequence $(R_1)_n-R_2-R_3-R_4$. These modifications can be used in producing wild-type protein C or activated protein C.

The coding sequence for protein C or activated protein C is then inserted into a suitable expression vector

which is, in turn, used to transfect a mammalian cell line. Expression vectors for use in carrying out the present invention will comprise a promoter capable of directing the transcription of a foreign gene introduced into a mammalian cell. Viral promoters are preferred due to their efficiency in directing transcription. A particularly preferred promoter is the major late promoter from adenovirus 2. Such expression vectors will also preferably contain a set of RNA splice sites located downstream from the promoter and upstream from the insertion site for the protein C sequence or within the protein C sequence itself. Preferred RNA splice sites may be obtained from adenovirus and/or immunoglobulin genes. Also contained in the expression vectors is a polyadenylation signal, located downstream of the insertion site. Viral polyadenylation signals are particularly preferred, such as the early or late polyadenylation signals from SV40 or the polyadenylation signal from the adenovirus 5 E1b region. In a particularly preferred embodiment, the expression vector also comprises a noncoding viral leader sequence, such as the adenovirus 2 tripartite leader, located between the promoter and the RNA splice sites. Preferred vectors may also include enhancer sequences, such as the SV40 enhancer and the sequences encoding the adenovirus VA RNAs.

Cloned gene sequences may then be introduced into cultured mammalian cells by, for example, calcium phosphate-mediated transfection (Wigler et al., *Cell* 14: 725, 1978; Corsaro and Pearson, *Somatic Cell Genetics* 7: 603, 1981; Graham and Van der Eb, *Virology* 52: 456, 1973). A precipitate is formed of the DNA and calcium phosphate, and this precipitate is applied to the cells. Some of the cells take up the DNA and maintain it inside the cell for several days. A small fraction of these cells (typically 10^{-4}) integrate the DNA into the genome. In order to identify these integrants, a gene that confers a selectable phenotype (a selectable marker) is generally introduced into the cells along with the gene of interest. Preferred selectable markers include genes that confer resistance to drugs, such as neomycin, hygromycin, and methotrexate. Selectable markers may be introduced into the cell on a separate plasmid at the same time as the gene of interest, or they may be introduced on the same plasmid. If on the same plasmid, the selectable marker and the gene of interest may be under the control of different promoters or the same promoter. In one embodiment, the selectable marker is placed on the same plasmid with the sequence encoding protein C such that both sequences are controlled by the same promoter, an arrangement known as a dicistronic message. Constructs of this type are known in the art (for example, European Patent Office publication 117,058). It may also be advantageous to add additional DNA, known as "carrier DNA," to the mixture which is introduced into the cells. After the cells have taken up the DNA, they are allowed to grow for a period of time, typically 1-2 days, to begin expressing the gene of interest. Drug selection is then applied to select for the growth of cells which are expressing the selectable marker in a stable fashion. Clones of such cells may be screened for expression of protein C.

Preferred mammalian cell lines for use in the present invention include the COS, BHK and 293 cell lines. In addition, a number of other cell lines may be used within the present invention, including Rat Hep I (ATCC CRL 1600), Rat Hep II (ATCC CRL 1548), TCMK (ATCC CCL 139), Human lung (ATCC CCL 75.1), Human hepatoma (ATCC HTB-52), Hep G2 (ATCC HTB 8065), Mouse liver (ATCC CC 29.1) and DUKX cells (Urlaub and Chasin, *Proc. Natl. Acad. Sci. USA* 77: 4216-4220, 1980).

The 293 cell line (ATCC CRL 1573; Graham et al., *J. Gen. Virol.* 36: 59-72, 1977) is particularly preferred, due to its ability to efficiently process protein C to the two-chain form. This cell line is transformed with human adenovirus 5 DNA and has the Ad5 E1A gene integrated into its genome. Preferred expression vectors for use with 293 cells will include an adenovirus promoter. Neomycin resistance is a preferred selectable marker for use in 293 cells. A preferred BHK cell line is the tk- BHK cell line BHK570 (Waechter and Baserga, *Proc. Natl. Acad. Sci. USA* 79: 1106-1110, 1982).

The copy number of the integrated gene sequence may be increased through amplification by using certain selectable markers (e.g., dihydrofolate reductase, which confers resistance to methotrexate). The selectable marker is introduced into the cells along with the gene of interest, and drug selection is applied. The drug concentration is then increased in a stepwise manner, with selection of resistant cells at each step. By selecting for increased copy number of cloned sequences, expression levels of the encoded protein may be substantially increased.

Protein C produced according to the present invention is preferably purified, as by affinity chromatography on an anti-protein C antibody column. Additional purification of the column eluate may be achieved by conventional chemical purification means, such as high-performance liquid chromatography (HPLC).

Protein C produced according to the present invention may be activated by removal of the activation peptide from the amino terminus of the heavy chain. Activation may be achieved by incubating protein C in the presence of α -thrombin (Marlar et al., *Blood* 59: 1067-1072, 1982), trypsin (Marlar et al., *ibid.*), Russell's viper venom factor X activator (Kisiel, *ibid.*) or the commercially available venom-derived activator Protac C (American Diagnostica).

To summarize the examples which follow, Example 1 describes the cloning of DNA sequences encoding human protein C. Example 2 describes the construction of a full-length coding sequence for protein C from the sequences isolated in Example 1. Example 3 describes the construction of expression vectors for the protein C DNA. Example 4 describes the production of protein C using transfected mammalian cells. Example 5 describes a full-length cDNA encoding protein C and its expression in transfected mammalian cells. Example 6 describes the production of activated protein C in BHK and 293 cells. Example 7 describes the production of protein C from a precursor having a modified cleavage site. Example 8 describes the use of the Factor VII pre-pro peptide or the prothrombin pre-pro peptide to direct the secretion of protein C from transfected cells.

EXAMPLES

Restriction endonucleases and other DNA modification enzymes (e.g., T₄ polynucleotide kinase, calf alkaline phosphatase, Klenow DNA polymerase, T₄ polynucleotide ligase) were obtained from Bethesda Research Laboratories (BRL) and New England Biolabs and were used as directed by the manufacturer, unless otherwise noted.

Oligonucleotides may be synthesized on an Applied Biosystems Model 380 A DNA synthesizer and purified by polyacrylamide gel electrophoresis on denaturing gels. *E. coli* cells may be transformed as described by Maniatis et al. (Molecular Cloning: A Laboratory Manual, Cold Spring Harbor Laboratory, 1982). M13 and pUC cloning vectors and host strains were obtained from BRL.

Example 1**Cloning of DNA Sequences Encoding Human Protein C**

A cDNA coding for a portion of human protein C was prepared as described by Foster and Davie (*ibid.*). Briefly, a λ gt11 cDNA library was prepared from human liver mRNA by conventional methods. Clones were screened using ¹²⁵I-labeled affinity-purified antibody to human protein C, and phage were prepared from positive clones by the plate lysate method (Maniatis et al., *ibid.*), followed by banding on a cesium chloride gradient. The cDNA inserts were removed using Eco RI and subcloned into plasmid pUC9 (Vieira and Messing, *Gene* 19: 259-268, 1982). Restriction fragments were subcloned in the phage vectors M13mpl0 and M13mp11 (Messing, *Meth. in Enzymology* 101: 20-77, 1983) and sequenced by the dideoxy method (Sanger et al., *Proc. Natl. Acad. Sci. USA* 74: 5463-5467, 1977). A clone was selected which contained DNA corresponding to the known partial sequence of human protein C (Kisiel, *ibid.*) and encoded protein C beginning at amino acid 64 of the light chain and extending through the heavy chain and into the 3' non-coding region. This clone was designated λ HCI375. A second cDNA clone coding for protein C from amino acid 24 was identified. The insert from this clone was subcloned into pUC9 and the plasmid designated pHCA6L (Figure 1). This clone encodes a major portion of protein C, including the heavy chain coding region, termination codon, and 3' non-coding region.

The cDNA insert from λ HCI375 was nick translated using α -³²P dNTP's and used to probe a human genomic library in phage λ Charon 4A (Maniatis et al., *Cell* 15: 687-702, 1978) using the plaque hybridization procedure of Benton and Davis (*Science* 196: 181-182, 1977) as modified by Woo (*Meth. in Enzymology* 68: 381-395, 1979). Positive clones were isolated and plaque-purified (Foster et al., *Proc. Natl. Acad. Sci. USA* 82: 4673-4677, 1985, herein incorporated by reference). Phage DNA prepared from positive clones (Silhavy et al., in *Experiments with Gene Fusion*, Cold Spring Harbor Laboratory, 1984) was digested with Eco RI or Bgl II and the genomic inserts purified and subcloned in pUC9. Insert restriction fragments were subcloned into M13 vectors and sequenced to confirm their identity and establish the DNA sequence of the entire gene.

The cDNA insert of pHCA6L was nick translated and used to probe the phage λ Charon 4A library. One genomic clone was identified which hybridized to probes made from the 5' and 3' ends of the cDNA. This phage clone was digested with Eco RI and a 4.4 kb fragment, corresponding to the 5' end of the protein C gene, was subcloned into pUC9. The resultant recombinant plasmid was designated pHCR4.4. Complete DNA sequence analysis revealed that the insert in pHCR4.4 comprised two exons of 70 and 167 base pairs separated by an intron of 1263 bp. The first exon encodes amino acids -42 to -19; the second encodes amino acids -19 to 37. Sequence analysis confirmed the DNA sequence of the entire protein C gene.

As noted above, it is then necessary to remove the intron in order to use a genomic clone to construct an acceptable coding sequence for use within the present invention.

Example 2**Construction of a Full-Length Coding Sequence for Protein C**

A full-length coding sequence for Protein C, including the pre-pro peptide, is constructed by joining the appropriate fragments of the cDNA and genomic clones. This is accomplished by removing the intron from the genomic clone (pHCR4.4) and joining the fused exons to the cDNA (from pHCA6L) at convenient restriction sites. The desired genomic:cDNA junction is then generated by looping out unwanted sequences by oligonucleotide-directed deletion mutagenesis.

Plasmid pHCA6L contains the protein C partial cDNA cloned in the Eco RI site of pUC9 (Figure 1). The cDNA insert is subcloned in two fragments to prepare it for joining to the 5'-most coding region from the genomic clone. Plasmid pHCA6L is digested with Eco RI and Sal I, and the reaction mixture is extracted with phenol and CHCl₃, then ethanol-precipitated. The resulting DNA fragments are resuspended in ligation buffer, and T₄ DNA ligase is added. The ligation mixture is incubated at 15°C for 14 hours. An aliquot of the ligation mix is used to transform *E. coli* JM83, and the cells are plated on LB agar containing X-gal. White colonies are selected, and plasmid DNA is prepared. The DNA is analyzed by restriction enzyme digestion to identify clones containing the 3' portion of the cDNA (ca. 1450 bp insert) and the 5' portion of the cDNA (ca. 65 bp insert). These clones are designated p9C3' and p9C5', respectively (Figure 6).

The 5' coding region missing from the cDNA is contained in exons I and II of the genomic clone pHCR4.4. This plasmid contains an insert of approximately 4400 base pairs and terminates on its 3' end at an Eco RI site located in intron B.

To remove the coding sequences from pHCR4.4, the plasmid is digested with PstI and Eco RI and the resulting fragments are separated by electrophoresis in an agarose gel. The ca. 2540 bp fragment containing exons I and II is isolated from the gel and extracted with CTAB (Langridge, et al., *Analyt. Biochem.* 103: 264, 1980). This fragment, designated 5'P-R, is subcloned into pUC9 to produce plasmid p5'P-R (figure 7).

The intron in p5'P-R (designated intron A), is removed in a two-step process (Figure 7). The plasmid is digested with Apa I, which cleaves at a unique site in the intron and leaves 3' overhanging ends. The linearized plasmid is then treated with Bal 31 exonuclease or T₄ polymerase to remove approximately 400 bp from each end and the resultant fragment ends are blunted with S1 nuclease. The linearized plasmid is recircularized with ligase and used to transform *E. coli* JM83. Plasmid DNA is extracted and analyzed for the presence of the Sma I and Sst I restriction sites in intron A, and a plasmid having a Sma I-Sst I fragment reduced to 300-400 bp is chosen and designated p5'PΔA_R.

The remainder of intron A is removed by oligonucleotide-directed deletion mutagenesis, essentially as described by Zoller and Smith (*Manual for Advanced Techniques in Molecular Cloning Course*, Cold Spring Harbor Laboratory, 1983) for the two-primer method. p5'PΔA_R is digested with Pst I and Eco RI, and the protein C fragment is subcloned into Pst I + Eco RI-digested M13mp9. Plus strand phage DNA is prepared as template and annealed to oligonucleotide mut-1 (Table I). This mutagenic oligonucleotide comprises sequences complementary to the exon I and II sequences to be joined. The M13 universal sequencing primer is annealed 3' to mut-1 on the same template. The primers are extended using DNA polymerase I (Klenow fragment) and nucleoside triphosphates in the presence of T4 DNA ligase. The resulting duplex DNA circles are transformed into *E. coli* JM103 and the resulting plaques screened under stringent hybridization conditions using the 32p-labeled mutagenic oligonucleotide as probe. DNA from positive plaques is isolated and sequenced using oligonucleotide primer-1 (Table I), which primes in exon II, allowing the determination of the DNA sequence across the deletion junction. A molecule having the correct inframe fusion of exons I and II is selected. The PstI-EcoRI fragment is isolated from the M13 replicative form by restriction endonuclease digestion and agarose gel electrophoresis and is subcloned into pUC9 to produce plasmid p5'I-II (Figure 7).

Referring to Figure 8, to join the 5' coding region to the cDNA, the ca. 1277 bp Pst I-Eco RI fragment of p5'I-II is isolated from a Pst I + Eco RI digest of the plasmid and purified by agarose gel electrophoresis. The 65 bp 5'-most cDNA fragment is isolated from a Sal I + Eco RI digest of p9C5' and purified by electrophoresis on an acrylamide gel. The two fragments are ligated at their Eco RI termini, and the resulting ca. 1330 bp Pst I-Sal I fragment is subcloned into Pst I + Sal I-digested M13mp9 (Figure 8). Plus strand phage DNA is prepared as template for oligonucleotide-directed deletion mutagenesis. Oligonucleotide mut-2 (Table I) is annealed to the template, and oligonucleotide mut-3 (Table I) is annealed upstream as second primer. The primers are extended as described above. Oligonucleotide mut-2 directs the fusion of exon II sequences encoding amino acids 23-26 to the cDNA at codon 27. The second primer (mut-3) introduces an Eco RI site 35 bp upstream from the start of translation. The resulting phage are screened for the absence of Nco I and Xho I sites and for the presence of the introduced Eco RI site. Phage DNA showing the desired restriction pattern is sequenced using primer-2 (Table I) to verify the presence of the correct junction between exon II and the cDNA. Phage DNA with the correct sequence is selected, and the Pst I-Sal I fragment comprising the 5' coding region is isolated from the replicative form of the M13 recombinant phage. The fragment is purified by agarose gel electrophoresis and inserted into Pst I + Sal I-digested pUC9 to produce plasmid pC5'end.

Referring to Figure 9, plasmid pC5'end is digested with EcoRI and Sal I, and the 5' protein C fragment is purified by agarose gel electrophoresis and extraction with CTAB. The remainder of the cDNA is isolated as a Sal I - Eco RI fragment from p9C3'. The two fragments are joined in a three-part ligation to Eco RI-digested pUC9. The ligation mixture is used to transform *E. coli* JM83, the cells are plated on LB + X-gal, and plasmid DNA is isolated from white colonies. The resultant plasmid is designated pMMC. It contains the complete coding sequence for human protein C on a ca. 1500 bp Eco RI fragment.

TABLE I

OligonucleotideSequence

mut-1	3'CGA CGA GAA CTG AGT CAC AA5'
mut-2	3'CTG AAG CTC CTC CGG TTC CTT TAA5'
mut-3	5'GGA GGA ATT CTG AGC3'
primer-1	5'TTT GCG GAT CCG CAG3'
primer-2	5'CGA CGT GCT TGG ACC3'

Example 3

Construction of Expression Vectors for Protein C

The protein C-encoding insert is removed from pMMC as an Eco RI fragment and inserted into a suitable mammalian cell expression vector. An exemplary vector is pD7, comprising the SV40 enhancer and the adenovirus 2 major late promoter and tripartite leader.

Plasmid pD7 is generated from plasmid pDHFRIII (Berkner and Sharp, Nuc. Acids. Res. 13: 841-857, 1985). The Pst I site immediately upstream from the DHFR sequence in pDHFRIII was converted to a Bcl I site by digesting 10 ug of plasmid with 5 units of Pst I for 10' at 37°C in 100 ul buffer A (10 mM Tris pH 8, 10 mM MgCl₂, 6 mM NaCl, 7mM β-MSH). The DNA was phenol extracted, EtOH precipitated, and resuspended in 40 ul buffer B (50 mM Tris pH 8, 7 mM MgCl₂, 7mM β-MSH) containing 10 mM dCTP and 16 units T₄ DNA polymerase and incubated at 12°C for 60 minutes. Following EtOH precipitation, the DNA was ligated to 2.5 ug kinased Bcl I linkers in 14 ul buffer C (10 mM Tris pH 8, 10 mM MgCl₂, 1 mM DTT, 1.4 mM ATP) containing 400 units T₄ polynucleotide ligase for 12 hours at 12°C. Following phenol extraction and EtOH precipitation, the DNA was resuspended in 120 ul buffer D (75 mM KCl, 6 mM Tris pH 7.5, 10 mM MgCl₂, 1 mM DTT), digested with 80 units Bcl I for 60 minutes at 50°C, then electrophoresed through agarose. Form III plasmid DNA (10 ug) was isolated from the gel, and ligated in 10 ul buffer C containing 50 units T₄ polynucleotide ligase for 2 hours at 12°C, and used to transform *E. coli* HB101. Positive colonies were identified by rapid DNA preparation analysis, and plasmid DNA (designated pDHFR') prepared from positive colonies was transformed into dAM- *E. coli*.

Plasmid pD2' was then generated by cleaving pDHFR'(15 ug) and pSV40 (comprising Bam HI digested SV40 DNA cloned into the Bam HI site op pML-I) (25 ug) in 100 ul buffer D with 25 units Bcl I for 60 minutes at 50°C, followed by the addition of 50 units Bam HI and additional incubation at 37°C for 60 minutes. DNA fragments were resolved by agarose gel electrophoresis, and the 4.9 kb pDHFR' fragment and 0.2 kb SV40 fragment were isolated. These fragments (200 ng pDHFR' DNA and 100 ng SV40 DNA) were incubated in 10 ul buffer C containing 100 units T₄ polynucleotide ligase for 4 hours at 12°C, and the resulting construct (pD2') was used to transform *E. coli* RRI.

Plasmid pD2' was modified by deleting the "poison" sequences in the pBR322 region (Lusky and Botchan, Nature 293: 79-81, 1981). Plasmids pD2' (6.6 ug) and pML-I (Lusky and Botchan, *ibid.*) (4 ug) were incubated in 50 ul buffer A with 10 units each Eco RI and Nru I for 2 hours at 37°C, followed by agarose gel electrophoresis. The 1.7 kb pD2' fragment and 1.8 kb pML-I fragment were isolated and ligated together (50 ng each) in 20 ul buffer C containing 100 units T₄ polynucleotide ligase for 2 hours at 12°C, followed by transformation into *E. coli* HB101. Colonies containing the desired construct (designated pD2) were identified by rapid preparation analysis. Ten ug of pD2 were then digested with 20 units each Eco RI and Bgl II, in 50 ul buffer A for 2 hours at 37°C. The DNA was electrophoresed through agarose, and the desired 2.8 kb fragment (fragment C) comprising the pBR322, 3' splice site and poly A sequences was isolated.

To generate the remaining fragments used in constructing pD3, pDHFRIII was modified to convert the Sac II (Sst II) site into either a Hind III or Kpn I site. Ten ug pDHFRIII were digested with 20 units Sst II for 2 hours at 37°C, followed by phenol extraction and ethanol precipitation. Resuspended DNA was incubated in 100 ul buffer B containing 10 mM dCTP and 16 units T₄ DNA polymerase for 60 minutes at 12°C, phenol extracted, dialyzed, and ethanol precipitated. DNA (5 μg) was ligated with 50 ng kinased Hind III or Kpn I linkers in 20 ul buffer C containing 400 units T₄ DNA ligase for 10 hours at 12°C, phenol extracted, and ethanol precipitated. After resuspension in 50 ul buffer A, the resultant plasmids were digested with 50 units Hind III or Kpn I, as appropriate, and electrophoresed through agarose. Gel-isolated DNA (250 ng) was ligated in 30 ul buffer C containing 400 units T₄ DNA ligase for 4 hours at 12°C and used to transform *E. coli* RRI. The resultant plasmids were designated pDHFRIII (Hind III) and pDHFRIII (Kpn I). A 700 bp Kpn I-Bgl II fragment (fragment A) was then purified from pDHFRIII (Kpn I) by digestion with Bgl II and Kpn I followed by agarose gel electrophoresis.

The SV40 enhancer sequence was inserted into pDHFRIII (Hind III) as follows: 50 ug SV40 DNA was incubated in 120 ul buffer A with 50 units Hind III for 2 hours at 37°C, and the Hind III C SV40 fragment (5089-968 bp) was gel purified. Plasmid pDHFRIII (Hind III) (10 ug) was treated with 250 ng calf intestinal phosphatase for 1 hour at 37°C, phenol extracted and ethanol precipitated. The linearized plasmid (50 ng) was ligated with 250 ng Hind III C SV40 in 16 ul buffer C for 3 hours at 12°C, using 200 units T₄ polynucleotide ligase, and transformed into *E. coli* HB101. A 700 base pair Eco RI-Kpn I fragment (fragment B) was then isolated from this plasmid.

For the final construction of pD3, fragments A and B (50 ng each) were ligated with 10 ng fragment C with 200 units T₄ polynucleotide ligase for 4 hours at 12°C, followed by transfection of *E. coli* RRI. Positive colonies were detected by rapid preparation analysis, and a large-scale preparation of pD3 was made.

Plasmid pD3 is modified to accept the insertion of the protein C sequence by converting the Bcl I insertion site to an Eco RI site. It is first necessary to remove the Eco RI site present in pD3 at the leftmost terminus of the adenovirus 5' 0-1 map unit sequences by converting it to a Bam HI site via conventional linking procedures. Briefly, the plasmid is digested with Eco RI and the linearized DNA treated with T₄ DNA polymerase and all four deoxynucleotide triphosphates to generate blunt termini. The plasmid is then ligated to octonucleotides comprising the Bam HI restriction site, the DNA digested with Bam HI to remove excess linkers, and the fragment comprising the mammalian cell expression sequences is cloned into the Bam HI site of pML-I. The resultant plasmid is transformed into *E. coli* HB101, and plasmid DNA is prepared and screened for the correct conversion. In a similar manner, the Bcl I site is converted to an Eco RI site using appropriate octonucleotide linkers. The resultant vector is known as pD7. The 1.5 kb protein C Eco RI fragment from pMMC

is then inserted into the Eco RI site of pD7 to produce the expression vector pD7C (Figure 10).

A vector enabling expression of the protein C sequence from a polycistronic message is constructed by using pD5, a plasmid similar to pD3 which contains a DHFR coding sequence lacking most of the 5' non-coding region. The DHFR sequence is further modified to reduce its binding affinity to methotrexate.

The vector pD5 is constructed by a method analogous to that described for pD3, and differs from pD3 only in that a Bam HI site is the site of insertion of heterologous DNAs, and that the BC-I-Bam: HI SV40 fragment containing the SV40 polyadenylation signal is in the late orientation.

The DHFR sequence is modified by first digesting pDHFRIII with Pst I and Sst I and isolating the 400 bp DHFR fragment. This is subcloned in an M13 phage vector and mutagenized as described by Simonsen and Levinson (Proc. Natl. Acad. Sci. USA 80: 2495-2499, 1983). Mutagenesis results in a single base pair change in the DHFR sequence. The altered fragment is then reinserted into pDHFRIII to produce plasmid pDHFRrIII.

The 5' non-coding region of the DHFR sequence is then removed. Plasmid pDHFRrIII is cleaved with Fnu 4HI, which cuts the plasmid at approximately 20 sites, then treated with T₄ DNA polymerase and all four deoxynucleotide triphosphates to generate blunt termini. Bam HI linkers are ligated to the ends, and the mixture digested with Bam HI and Nco I. A 0.6 kb Bam HI-Nco I fragment comprising the DHFR^r cDNA is isolated. Plasmid pDHFRrIII is digested with Nco I and Bam HI and the 0.2 kb fragment comprising the SV40 polyadenylation signal is isolated. The polyadenylation signal, in the early orientation, is then ligated to the DHFR^r fragment. After digestion with Bam HI, the resultant Bam HI fragment is then inserted into the Bam HI site of pD5 and the ligation mixture used to transform *E. coli* HB101. Plasmid DNA is prepared and screened by restriction endonuclease digestion. A plasmid having the DHFR^r insert in the correct orientation for transcription from the Ad2 major late promoter is designated pD5(DHFR^r).

To express protein C using plasmid pD5(DHFR^r), pMMC is digested with Eco RI and the 1.5 kb protein C fragment is isolated. The Eco RI termini are converted to Bcl I termini by linker ligation. Plasmid pD5(DHFR^r) is partially digested with Bam HI to cleave it at the 5' and of the DHFR^r sequence and is ligated to the protein C fragment. Plasmid DNA is screened for the proper orientation and insertion of the protein C fragment. The resultant vector, designated pD5(PC-DHFR^r), is illustrated in Figure 11.

Example 4

Expression of Protein C in Transfected Mammalian Cells

Baby hamster kidney (BHK) cells (American Type Culture Collection accession number CCL10) are transfected with pD7C by calcium phosphate co-precipitation (Wigler et al., *Cell* 14: 725, 1978; Corsaro and Pearson, *Somatic Cell Genetics* 7: 603, 1981; and Graham and Van der Eb, *Virology* 52: 456, 1973). The cells are grown at 37°C, 5% CO₂ in Dulbecco's medium (plus 10% heat-inactivated fetal calf serum and supplemented with L-glutamine and penicillin-streptomycin) in 60 mm tissue culture Petri dishes to a confluency of 20%. A total of 10 µg of DNA is used to transfect one 60 mm dish: 3.75 µg of pD7C, 1.25 µg of pKO-neo (Southern and Berg, *J. Mol. Appl. Genet* 1: 327-341, 1982) and 5 µg of salmon sperm DNA. The DNAs are precipitated in 0.3 M NaOAc, 75% ethanol, rinsed with 70% ethanol and redissolved in 20 µl 10 mM Tris-HCl pH 8, 1 mM EDTA. The DNA is combined with 440 µl H₂O and 500 µl of 280 mM NaCl, 1.5 mM NaH₂PO₄, 12 mM dextrose, 50 mM HEPES pH 7.12. Sixty µl of 250 mM CaCl₂ are added dropwise to the above mixture and the solution is allowed to stand at room temperature for 30 minutes. The solution is then added to the cells and the cells returned to 37°C for 4 hours. The medium is removed and 5 ml of 20% DMSO in Dulbecco's with serum are added for 2 minutes at room temperature. The dish is then washed rapidly with 2 changes of medium and incubated in fresh medium overnight. Twenty-four hours after the addition of the DNA, the medium is removed and selective medium (10 mg/ml of G418, 498 u/mg, Gibco, in Dulbecco's with serum) added. After approximately 10-13 days, individual clones, representing cells that have incorporated the pKO-neo gene and are thus resistant to G418, are transferred to 96-well plates and grown up for protein assays in Dulbecco's plus 10% fetal calf serum.

To assay for protein C, the medium is separated from the cells and cellular debris by centrifugation, and assayed for protein C polypeptide and biological activity. The cells are removed from the plates with trypsin, washed with fresh medium, centrifuged and frozen at -20°C. For assay, the cell pellets are thawed in PBS, pelleted, and resuspended in PBS containing 0.25% Triton X-100. Samples are diluted and assayed for polypeptide and activity.

The enzyme-linked immunosorbent assay (ELISA) for protein C is done as follows: Affinity-purified polyclonal antibody to human protein C (100 µl of 1 µg/ml in 0.1 M Na₂CO₃, pH 9.6), is added to each well of 96-well microtiter plates and the plates are incubated overnight at 4°C. The wells are then washed three times with PBS (5 mM phosphate buffer, pH 7.5, 0.15 M NaCl) containing 0.05% Tween-20 and then incubated with 100 µl of 1% bovine serum albumin, 0.05% Tween 20 in PBS at 4°C overnight. The plates are then rinsed several times with PBS, air dried, and stored at 4°C. To assay samples, 100 µl of each sample is incubated for 1 hour at 37°C in the coated wells and the wells are rinsed with 0.05% Tween-20 in PBS. The plates are then incubated for 1 hour at 37°C with a biotin-conjugated sheep polyclonal antibody to protein C (30 ng/ml) in PBS containing 1% bovine serum albumin and 0.05% Tween-20. The wells are rinsed with PBS and incubated again for 1 hour at 37°C with avidin conjugated to alkaline phosphatase in PBS containing 1% bovine serum albumin and 0.05% Tween-20. The wells are then rinsed with PBS, and alkaline phosphatase activity is measured by the addition of 100 µl of phosphatase substrate (Sigma 104; 600 µg/ml) in 10% diethanolamine, pH 9.8, containing 0.3 mM MgCl₂. The absorbance at 405 nm is read on a microtiter plate reader.

Protein C biological activity is assayed by its ability to prolong the kaolin-cephalin clotting time of plasma following its activation as described in Example 5C.

Example 5

Expression of a Full Length cDNA Encoding Protein C

A. Isolation of cDNA.

A genomic fragment containing an exon corresponding to amino acids -42 to -19 of the pre-pro peptide (Exon I in Figure 4) of protein C was isolated, nick translated, and used as a probe to screen a cDNA library constructed by the technique of Gubler and Hoffman (Gene 25: 263-269, 1983) using mRNA from HEPG2 cells. This cell line was derived from human hepatocytes and was previously shown to synthesize protein C (Fair and Bahnak, Blood 64: 194-204, 1984). Ten positive clones comprising cDNA inserted into the Eco RI site of phage λ gt11 were isolated and screened with an oligonucleotide probe corresponding to the 5' non-coding region of the protein C gene. One clone was also positive with this probe and its entire nucleotide sequence was determined. The cDNA contained 70 bp of 5' untranslated sequence, the entire coding sequence for human prepro-protein C, and the entire 3' non-coding region corresponding to the second polyadenylation site (Figure 2).

B. Expression Vector Construction.

The expression of protein C cDNA was achieved in the vector pDX. This vector was derived from pD3 (described in Example 3 above) and pD3', a vector identical to pD3 except that the SV40 polyadenylation signal (i.e., the SV40 BamHI [2533 bp] to Bcl I [2770 bp] fragment) is in the late orientation. Thus, pD3' contains a Bam HI site as the site of gene insertion.

To generate pDX, the Eco RI site in pD3' was converted to a Bcl I site by Eco RI cleavage, incubation with SI nuclease, and subsequent ligation with Bcl I linkers. DNA was prepared from a positively identified colony, and the 1.9 kb Xho I-Pst I fragment containing the altered restriction site was prepared via agarose gel electrophoresis. In a second modification, Bcl I-cleaved pD3 was ligated with kinased Eco RI-Bcl I adaptors (constructed from oligonucleotides ZC525, 5'GGAATTC3'; and ZC526, 5'GATCAGAATTCC3') in order to generate an Eco RI site as the position for inserting a gene into the expression vector. Positive colonies were identified by restriction endonuclease analysis, and DNA from this was used to isolate a 2.3 kb Xho I-Pst I fragment containing the modified restriction site. The two above-described DNA fragments were incubated together with T₄ DNA ligase, transformed into *E. coli* HB101 and positive colonies were identified by restriction analysis. A preparation of such DNA, termed pDX, was then made. This plasmid contains a unique Eco RI site for insertion of foreign genes.

The protein C cDNA was then inserted into pDX as an Eco RI fragment. Recombinant plasmids were screened by restriction analysis to identify those having the protein C insert in the correct orientation with respect to the promoter elements and plasmid DNA (designated pDX/PC) was prepared from a correct clone (Figure 12). Because the cDNA insert in pDX/PC contains an ATG codon in the 5' non-coding region (see Figure 2), deletion mutagenesis was performed on the cDNA prior to transfection and expression experiments. Deletion of the three base pairs was performed according to standard procedures of oligonucleotide-directed mutagenesis. The pDX-based vector containing the modified cDNA was designated p594.

C. cDNA Expression.

Plasmid p594 was transfected into COS-1 (ATCC CRL1650), BHK and 293 cells by calcium phosphate precipitation. Four hours later, fresh culture media (supplemented with 5 μ g/ml vitamin K) were added. At appropriate times (usually 48 or 72 hours), the culture media were harvested and the cells were collected and lysed.

The protein C secreted into the culture medium was assayed by ELISA using the same affinity-purified polyclonal antibody which was used in the initial identification of the cDNA clones. Results of the assays of COS-1 cells.

To assess the extent of gamma-carboxylation of the recombinant protein, samples of the culture media were subjected to barium citrate precipitation, a process which selectively precipitates only gamma-carboxylated proteins from plasma (Bajaj et al., J. Biol. Chem. 256: 253-259, 1981). Over 70% of the protein C antigenic material could be precipitated with barium citrate.

The recombinant protein C was assayed for anti-coagulant activity by measuring its ability to prolong coagulation. Dialyzed media samples were treated with Protac C (American Diagnostica) to activate the protein C. The samples were then added to an *in vitro* clotting assay (Sugo et al., J. Biol. Chem. 260: 10453, 1985). Briefly, 50 μ l each of normal pooled human plasma, rabbit brain cephalin (10 mg/ml in TBS [50mM Tris pH 7.5, 150 mM NaCl]) and kaolin suspension (5 mg/ml in TBS) were mixed in a siliconized glass tube. After preincubation at 37°C for 2 minutes, 100 μ l of activated protein C diluted in TBS was added and the 37°C incubation was continued for an additional 2 minutes. Clotting was then initiated by the addition of 50 μ l of 25 mM CaCl₂, and the clotting time was recorded. The activity of the recombinant material was shown to be essentially the same as that of naturally occurring protein C.

Protein C produced by transfected BHK and 293 cells was further analyzed by Western blotting. Media samples were electrophoresed on denaturing gels and blots were prepared and probed with radiolabeled antibody to protein C. Results indicated that about 20% of the protein C from BHK cells was in the two-chain form, while about 90% of that from 293 cells was processed to the two-chain form.

TABLE 2
TRANSIENT EXPRESSION AND SECRETION OF PROTEIN C
IN COS-1 and 293 CELLS

<u>cells</u>	<u>plasmid</u>	<u>ng/ml protein C in media</u>
COS-1	none	0
COS-1	p594	10
293	none	0
293	p594	50

Example 6

Expression of Activated Protein C

The cDNA sequence for protein C was altered by site-specific mutagenesis to delete the portion encoding the activation peptide. The altered sequence was then transfected into BHK and 293 cells and stably transfected cells were selected. Active protein C was detected in culture media samples from both cell lines.

To delete the activation peptide coding sequence, plasmid p594 was digested with Sst I and the ~880 bp fragment was purified and inserted into the Sst I site of M13mp10. The 12 activation peptide codons were deleted by oligonucleotide-directed deletion mutagenesis (Zoller and Smith, *DNA* 3: 479-488, 1984) using the mutagenic oligonucleotide 5'-CTGAAACGACTCATTGAT3'. Replicative form DNA was prepared from mutant phage clones and digested with Sst I. The protein C fragment (~840 bp) was isolated and inserted into Sst I digested p594. The resultant plasmids were screened for proper orientation of the Sst I fragment by restriction mapping using Bgl II. A correct plasmid was selected and designated pPC829. Plasmid pPC829 was sequenced to verify the presence of the desired coding sequence.

Plasmid pPC829 was co-transfected into BHK cells (with plasmid pSVDHFR (Lee et al., *Nature* 294: 228-232, 1981)) and 293 cells (with pKO-neo (Southern and Berg, *J. Mol. Appl. Genet.* 1: 327-341, 1982)) by calcium phosphate coprecipitation (Graham and van der Eb, *Virology* 52: 456-467, 1973). After 48 hours, culture media were harvested and assayed for protein C by ELISA. Results are shown in Table 3. At the same time, cultures were split 1:5 into media containing 500 µg/ml of G418 (293 cells) or 250 nM methotrexate (BHK cells). After 10 days in the presence of selective media, stably transfected colonies were screened for protein C production by immunofilter assay (McCracken and Brown, *BioTechniques*, 82-87, March/April 1984). Plates were rinsed with PBS or No Serum medium (Dulbecco's plus penicillin-streptomycin, 5 µg/ml vitamin K). Teflon® mesh was then placed over the cells. Nitrocellulose filters were wetted with PBS or No Serum medium, as appropriate, and placed over the mesh. After four hours' incubation at 37°C, filters were removed and placed in buffer A (50 mM Tris pH 7.4, 5 mM EDTA, 0.05% NP-40, 150 mM NaCl, 0.25% gelatin) for 30 minutes at room temperature. The filters were incubated for 1 hour at room temperature, with shaking, in biotin-labeled sheep polyclonal antibody to protein C, 1 µg/ml in buffer A. Filters were then washed in buffer A and incubated 1 hour at room temperature, with shaking, in avidin-conjugated horseradish peroxidase (Boehringer-Mannheim), 1:1000 in buffer A. Filters were washed in buffer B, then in H₂O, and incubated in color reagent (60 mg HRP color development reagent [Bio-Rad], 20 ml methanol, 100 µl H₂O₂ in 100 ml 50 mM Tris pH 7.4, 150 mM NaCl). The reaction was stopped by transferring the filters to H₂O.

Positive colonies were picked and grown in selective media (containing 500 µg/ml G418 or 250 nM methotrexate, as appropriate) for 10 days. Culture media were assayed for APC activity by chromogenic assay. Media samples were added to microtiter wells containing 100 µl of 0.2 mM Spectrozyme PCa (American Diagnostica #336) in 50 mM Tris pH 7.5, 150 mM NaCl. Plates were incubated at 37°C and the A₄₀₅ measured at various time intervals. Representative results from one transfected 293 cell line (designated 829-20) are shown in Figure 13. Media from positive colonies of line 829-20 consistently showed higher activity with the

chromogenic substrate for APC than did control media which had been incubated with non-transfected 293 cells for the same length of time (10 days).

TABLE 3

TRANSIENT EXPRESSION OF ACTIVATED PROTEIN C (ELISA)

<u>Cell Line</u>	<u>Protein C ng/ml in Media</u>
BHK	2.7
293	30

Example 7

Modification of the Protein C Processing Site

A. Site-Specific Mutagenesis.

To enhance the processing of single-chain protein C to the two-chain form, two additional arginine residues were introduced into the protein, resulting in a cleavage site consisting of four basic amino acids. The resultant mutant precursor of protein C was designated PC962. It contains the sequence Ser-His-Leu-Arg-Arg-Lys-Arg-Asp at the cleavage site. Processing at the Arg-Asp bond results in a two-chain protein C molecule.

The mutant molecule was generated by altering the cloned cDNA by site-specific mutagenesis (essentially as described by Zoller and Smith, DNA 3: 479-488, 1984, for the two-primer method) using the mutagenic oligonucleotide ZC962 (5'-AGTCACCTGAGAAGAAAACGAGACA3'). Plasmid p594 was digested with Sst I and the approximately 87 bp fragment was cloned into M13mp1 and single-stranded template DNA was isolated. Following mutagenesis, a correct clone was identified by sequencing. Replicative form DNA was isolated, digested with Sst I, and the protein C fragment was inserted into Sst I-cut p594. Clones having the Sst I fragment inserted in the desired orientation were identified by restriction enzyme mapping. The resulting expression vector was designated pDX/PC962 (Figure 14).

B. Expression and Characterization of Protein C.

Plasmid pDX/PC962 was co-transfected into tk- BHK cells with pSV2-DHFR (Subramani et al., Mol. Cell Biol. 1: 854-864, 1981) by the calcium phosphate procedure (essentially as described by Graham and van der Eb, *ibid.*). The transfected cells were grown in Dulbecco's modified Eagle's medium (MEM) containing 10% fetal calf serum, 1X PSN antibiotic mix (Gibco 600-5640), 2.0 mM L-glutamine and vitamin K (5 ug/ml). The cells were selected in 250 nM methotrexate (MTX) for 14 days, and the resulting colonies were screened by the immunofilter assay (Example 6). Six of the most intensely reacting colonies were picked by cylinder-cloning and grown individually in 10-cm plates. When the cultures were nearly confluent, protein C production levels were measured by ELISA. Results are given in Table 4.

TABLE 4

<u>Clone</u>	<u>Cell Number (x 10⁻⁷)</u>	<u>ELISA ng/ml</u>	<u>pg/cell/day</u>
962-1	1.1	2500	2.20
-2	0.8	1250	1.56
-3	1.2	1350	1.12
-4	1.2	550	0.46
-5	1.2	1550	1.30
-6	1.2	950	0.80

The clone BHK/962-I was grown in larger scale culture, and several hundred micrograms of protein C were purified by affinity chromatography on a column prepared by coupling 7 mg of polyclonal sheep antibody against human protein C to 2 grams of CNBr-activated Sepharose 4B (Pharmacia, Inc., Piscataway, NJ). Cell culture medium was applied to the column, the column was washed with 100 ml TBS, and the protein C was eluted with TBS containing 3 M KSCN or with pH 11.5 buffer. Western blot analysis demonstrated that the mutant protein C was approximately 95% in the two-chain form, compared to about 20% two-chain protein C obtained from BHK cells transfected with the native sequence.

Milligram quantities of protein C were purified from either stable BHK cell clones expressing the PC962 mutant protein or stable 293 cell clones expressing the wild-type protein C (p594 transfected cells) using a monoclonal antibody column specific for the calcium-induced conformation of protein C. Cell culture media were applied to the column in the presence of 5 mM CaCl_2 , the column was washed with TBS containing 5 mM CaCl_2 , and the protein C was eluted with TBS containing 10 mM EDTA. The use of this purification method permitted purification of completely active protein C without exposure to denaturing conditions. The purified protein C was analyzed by SDS/PAGE followed by silver staining and was shown to be > 95% pure.

The BHK-produced PC962 protein was assayed for its ability to be activated to a form which shows both amidolytic and anticoagulant activities. Affinity-purified protein samples were exhaustively dialyzed against TBS, then activated by incubation at 37°C for 1 hour with 0.1 volume of 1 unit/ml Protac C (American Diagnostica). Amidolytic activity was measured by adding aliquots of the activation mixture to 100 μl of 1 mM protein C substrate (Spectrozyme PCa, American Diagnostica) in a microtiter well and measuring the change in A405 over time using a microtiter plate reader. Anticoagulant activity of the activated protein C was assayed as described by Sugo et al. (ibid.). The affinity-purified pC962 protein was demonstrated to be fully active in both amidolytic and anticoagulant assays. Elution from the antibody column with pH 11.5 buffer was shown to yield a protein with higher activity than that obtained using 3 M KSCN elution.

Clonal cell lines from the pDX/PC962 transfection into BHK cells were also isolated by a process of limiting dilution. One plate of MTX-selected colonies (approximately 300 colonies) was trypsinized, counted, and re-plated into microtiter wells at an average of 0.5 cell/well. These were grown up in selective media containing 250 nM MTX. About 50% of the wells contained colonies. Wells containing identifiable colonies (1-2 mm diameter) were assayed by ELISA for protein C level in the media. For this assay, fresh medium was added to all the wells, allowed to incubate for 75 minutes, then removed and assayed. Five colonies which gave 75-minute accumulations of greater than 50 ng/ml (corresponding to over 1000 ng/ml/day) were split into 10-cm plates for larger scale culture. Protein C production levels for these clones ranged from 1.1 to 2.8 pg/cell/day.

A second plasmid, designated PC962/229, was constructed by inserting the PC962 cDNA into plasmid Zem229. Zem229 is a pUC18-based expression vector containing a unique Bam HI site for insertion of foreign DNA between the mouse metallothionein-I promoter and SV40 transcription terminator. Zem229 also contains an expression unit of the SV40 early promoter, mouse dihydrofolate reductase gene, and SV40 terminator. An Eco RI fragment containing the pC962 cDNA from pDX/PC962 was ligated, with Eco RI-Bam HI synthetic oligonucleotide adaptors, to Zem229, which had been cut with Bam HI and treated with phosphatase. The resulting vector is PC962/229, illustrated in Figure 14.

Plasmid PC962/229 was transfected into BHK cells by the calcium phosphate method. Cells were cultured in Dulbecco's MEM containing 10% fetal calf serum and 5 $\mu\text{g/ml}$ vitamin K. The 48-hour transient expression level from this transfection was approximately 25 ng/ml. After 2 days, the transfected cells were split into selective media containing 250 nM MTX and cultured for an additional 14 days. Three plates from this transfection, containing approximately 200 colonies each, were screened by the immunofilter assay, and the 24 most intensely reacting colonies were picked by cylinder cloning. These were grown individually in 10-cm plates, and their protein C production levels were measured. Colonies producing between 1.1 and 2.3 pg/cell/day were used for the production of stable protein C-producing cell lines.

Expression vector pDX/PC962 and plasmid pKO-neo were co-transfected by the calcium phosphate method into 293 cells. Transfected cells were split into media containing 500 $\mu\text{g/ml}$ G418 after 48 hours. After 10 days in selective media, immunofilter assays were done and two clones were picked by cylinder cloning. Protein C production was found to range from 1 to 2 pg/cell/day. The cultures were scaled up, and protein C was purified by immuno-affinity chromatography. Greater than 95% of the protein C was found to be in the two-chain form.

The structure of the 962 mutant protein prepared from BHK and 293 cells was compared to that of wild-type protein C from 293 cells and from plasma. Analysis by SDS/PAGE followed by silver staining showed that all the recombinant proteins contained heavy and light chains which co-migrated with those of the plasma protein. The wild-type protein C synthesized in 293 cells contained a significant amount (approximately 20%) of single-chain, unprocessed protein of $M_r = 66,000$, whereas the mutant protein produced in either cell type was essentially completely processed to two chains. N-terminal sequence analysis showed that both the light and heavy chains of the recombinant wild-type and BHK/PC962 mutant proteins were properly processed. The extent of gamma carboxylation of the recombinant proteins was measured by two distinct ELISA systems. The first system recognizes both gamma-carboxylated and non-carboxylated forms of the protein, while the second utilizes specific antibodies which only recognize protein C which has undergone a gla-induced conformational change in the presence of calcium. Analysis indicated that approximately 60% of the recombinant protein C produced in BHK cells and 90%-95% of that produced in 293 cells was sufficiently gamma carboxylated to be recognized by the specific antibodies.

The three recombinant proteins were also analyzed for amidolytic and anticoagulant activity and the results were compared to the activity of plasma protein C. PC962 from BHK cells and wild-type protein C from 293 cells both showed full amidolytic activity. In the anticoagulant assay, protein C from BHK cells had essentially the same specific activity as plasma protein C, whereas both wild-type and PC962 mutant proteins from 293 cells consistently exhibited approximately 40% greater specific activity.

C. Modification of Activated Protein C Processing Site.

A DNA sequence encoding an activated protein C precursor with the processing site sequence Arg-Arg-Lys-Arg was constructed by mutagenesis of the wild-type protein C sequence. The resultant sequence was analogous to that in pPC829, but lacked the portion encoding the activation peptide:

The protein C sequence present in plasmid p594 was altered in a single mutagenesis to delete the codons for the activation peptide and insert the Arg-Arg codons at the processing site. Mutagenesis was performed on the 870 bp Sst I fragment from p594 essentially as described in Example 7A using an oligonucleotide having the sequence 5' CGC AGT CAC CTG AGA AGA AAA CGA CTC ATT GAT GGG 3'.

The mutagenized sequence was used to construct expression vector pDX/PCI058 and the vector was co-transfected into BHK cells as described in Example 7B. The protein was purified on a polyclonal antibody column eluted with pH 11.5 buffer.

The activity of the 1058 protein was compared to that of activated plasma protein C and activated PC962. Plasma protein C and PC962 (5 µg/ml) were activated by treatment with 1/10 volume Protac C (American Diagnostica) for two hours. Anticoagulant activity was assayed by combining 50 µl human plasma with 50 µl activated protein C and incubating the mixtures at 38°C for 150 seconds. To this mixture was added 50 µl activated cephaloplastin (American Scientific Products, McGaw Park, IL) and the mixture was incubated at 37°C for 300 seconds. One hundred µl of 20 mM CaCl₂ was added and the clotting time was recorded. Data are presented in Figure 15.

Example 8

Use of the Factor VII and Prothrombin Pre-Pro Peptides to Secrete Protein C

The factor VII pre-pro peptide was substituted for the protein C pre-pro peptide in an effort to obtain higher yields of properly processed protein C. These hybrid constructs are then inserted into suitable expression vectors and transfected into mammalian cell lines.

A cDNA encoding factor VII has been described (Hagen et al., Proc. Natl. Acad. Sci. USA 83: 2412-2416, 1986). Clone HVII565 comprises the coding sequence for a 38 amino acid pre-pro peptide. This coding sequence was isolated as an Eco RI-Hha I fragment of 140 bp.

The protein C sequence was isolated from p594 by partial cleavage with Sst I and complete digestion with Eco RI. A 1540 bp fragment extending from the Sst I site at codon +7 to the Eco RI site 3' to the cDNA was isolated.

The factor VII and protein C sequences were then joined by means of an oligonucleotide linker which completes the coding sequence for amino acids -3 to -1 of the factor VII pre-pro peptide and amino acids 1-8 of protein C. The linker was constructed from two oligonucleotides having the sequences 5' CCGGCGCGCCAA-CI'CCTTCCTGGAGGAGCT3' and 5'CCTCCAGGAAGGAGTTGGCGCGCCGGCG3'. The two oligonucleotides were annealed and joined, in a four-part ligation, to the factor VII pre-pro sequence, protein C cDNA and pUC9 which had been cleaved with Eco RI and treated with bacterial alkaline phosphatase. The ligated DNA was used to transform *E. coli* (JM 101). Plasmid DNA was prepared and screened for the presence of a 1710 bp Eco RI fragment. A correct clone was designated p7/C-10.

The factor VII/protein C fusion was expressed in 293 cells. The Eco RI insert from plasmid p7/C-10 was ligated to Eco RI-digested pDX. The resulting expression vector was used to co-transfect 293 cells as previously described. Forty-eight hour expression levels were assayed by ELISA and compared to those of 293 cells transfected with the wild-type protein C expression construct and untransfected cells. Results are presented in Table 5.

TABLE 5

<u>Protein</u>	<u>ng/ml</u>
Factor VII/protein C	123
Wild-type protein C	187
Control	<1

The prothrombin leader sequence was constructed from the oligonucleotides listed in Table 6 and fused to the mature protein C coding sequence. The oligonucleotides were kinased by combining 50 ng of each

oligonucleotide with 1 unit of T4 kinase in 20 ul of kinase buffer containing 1 mM ATP. The reaction was allowed to proceed at 37°C for 30 minutes, then the mixture was heated to 65°C for 10 minutes to inactivate the kinase.

TABLE 6

ZC 1323	5' CCT CCA GGA AGG AGT TGG CTC GCC GGA 3'	5
ZC 1324	5' CGC GTC CGG CGA GCC AAC TCC TTC CTG GAG GAG CT 3'	10
ZC 1378	5' AAT TCC ACC ATG GCT CAT GTG AGA GGA CTG CAA CTG CCT GGC TGC CTG GCT CTG GCT GCT CTG TGC AGC CTG GTG CAC AGC CAG CAT GTG TTC CTG GCT CCT CAG CAG GCC AGG AGC CTG CTG CAA 3'	15 20
ZC 1379	5' CGC GTT GCA GCA GGC TCC TGG CCT GCT GAG GAG CCA GGA ACA CAT GCT GGC TGT GCA CCA GGC TGC ACA GAG CAG CCA GAG CCA GGC AGC CAG GCA GTT GCA GTC CTC TCA CAT GAG CCA TGG TGG 3'	25 30

The prothrombin leader was then assembled. Fifty ng of Eco RI, Sst I-cut M13mpl9 was combined with 2.5 ng each of the kinased oligonucleotides in 20 ul of ligase buffer containing 1 mM ATP and 4 units of T4 ligase. The mixture was incubated at 15°C for 48 hours and transformed into competent *E. coli* JM101 cells. A clear plaque was selected and phage DNA was prepared. DNA sequencing confirmed that the correct sequence had been constructed.

The prothrombin leader was then joined to the protein C sequence. RF DNA was prepared from the phage clone containing the synthesized leader and a 150 bp Eco RI-Sst I fragment was isolated. Plasmid p594 was digested to completion with Eco RI and partially digested with Sst I and the 1540 bp protein C fragment was recovered. These fragments were ligated with Eco RI-cut pDX and the ligation mixture was used to transform competent *E. coli* HB101 cells. Plasmid DNA was isolated from transformant colonies and analyzed by restriction digestion to confirm that the fragments had been assembled in the correct orientation.

From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not to be limited except as by the appended claims.

The features disclosed in the foregoing description, in the following claims and/or in the accompanying drawings may, both separately and in any combination thereof, be material for realizing the invention in diverse forms thereof.

Claims

1. A DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, said sequence further coding for the amino acid sequence (R1)n-R2-R3-R4, wherein R1, R2, R3 and R4 are Lys or Arg and n = 0, 1, 2 or 3, at the cleavage site between the light and heavy chains.

2. The DNA sequence of claim 1 wherein said amino acid sequence is Arg-Arg-Lys-Arg, at the cleavage site between the light and heavy chains.

3. A DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, said sequence further coding for the pre-pro peptide of a protein selected from the group consisting of factor VII, factor IX, factor X, prothrombin and protein S.

4. A DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, said protein further including the substitution of residue I58 with a non-acidic amino acid residue selected from the group consisting of Ala, Ser, Thr, and Gly.

5. A DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, said protein further including the substitution of residue I54 with a basic amino acid residue selected from the group consisting of Lys or Arg.

6. A DNA sequence which codes for a protein having substantially the same biological activity as human protein C or human activated protein C, said protein further including the substitution of Lys-Arg at residues I56-I57 with Lys-Lys or Arg-Arg.

7. An expression vector capable of integration in mammalian host cell DNA, said expression vector including a promoter followed downstream by a DNA sequence according to any of claims 1-6, said DNA sequence being followed downstream by a polyadenylation signal, wherein transcription of the DNA sequence is directed by the promoter.

8. Mammalian cells transfected with an expression vector according to claim 7.

9. The cells of claim 8 wherein said cells are selected from the group consisting of COS, BHK, Rat Hep I, Rat Hep II, TCMK, Human lung, Human hepatoma, Hep G2, Mouse liver, DUKX and 293 cells.

10. A method for producing a protein which, upon activation, has substantially the same structure and/or biological activity as human activated protein C, comprising:

introducing into a mammalian host cell an expression vector according to claim 7;

growing said mammalian host cell in an appropriate medium; and

isolating the protein product encoded by said expression vector and produced by said mammalian host cell.

11. The method of claim 10 wherein said cell is selected from the group consisting of COS, BHK, Rat Hep I, Rat Hep II, TCMK, Human lung, Human hepatoma, Hep G2, Mouse liver, DUKX and 293 cells.

12. A method for producing a protein which, upon activation, has substantially the same structure and/or biological activity as human activated protein C, comprising:

introducing into a BHK host cell an expression vector capable of integration into BHK host cell DNA, said expression vector including a promoter followed downstream by a DNA sequence according to any of claims 1, 5 or 6, said DNA sequence being followed downstream by a polyadenylation signal, wherein transcription of the DNA sequence is directed by the promoter;

growing said BHK host cell in an appropriate medium; and

isolating the protein product encoded by said DNA sequence and produced by said BHK host cell.

13. The method of claims 10-12, further comprising introducing into the host cell, with said expression vector, a selectable marker.

14. The method of claims 10-12, further comprising the step of activating the protein product to produce a protein having substantially the same biological activity as human activated protein C.

15. The method of claim 14 wherein the activating step comprises cleavage of the protein product with a protease selected from the group consisting of alpha-thrombin, trypsin, and venom activators.

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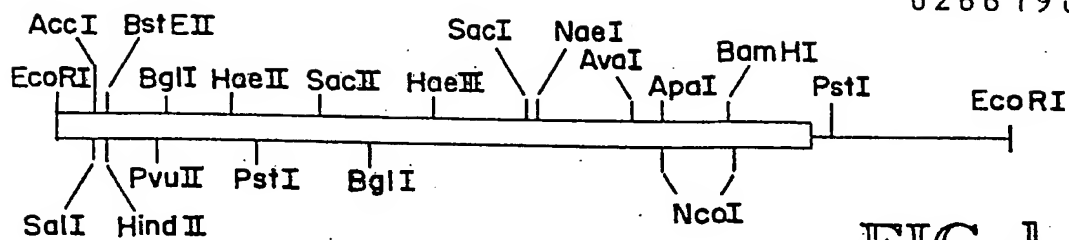


FIG. 1

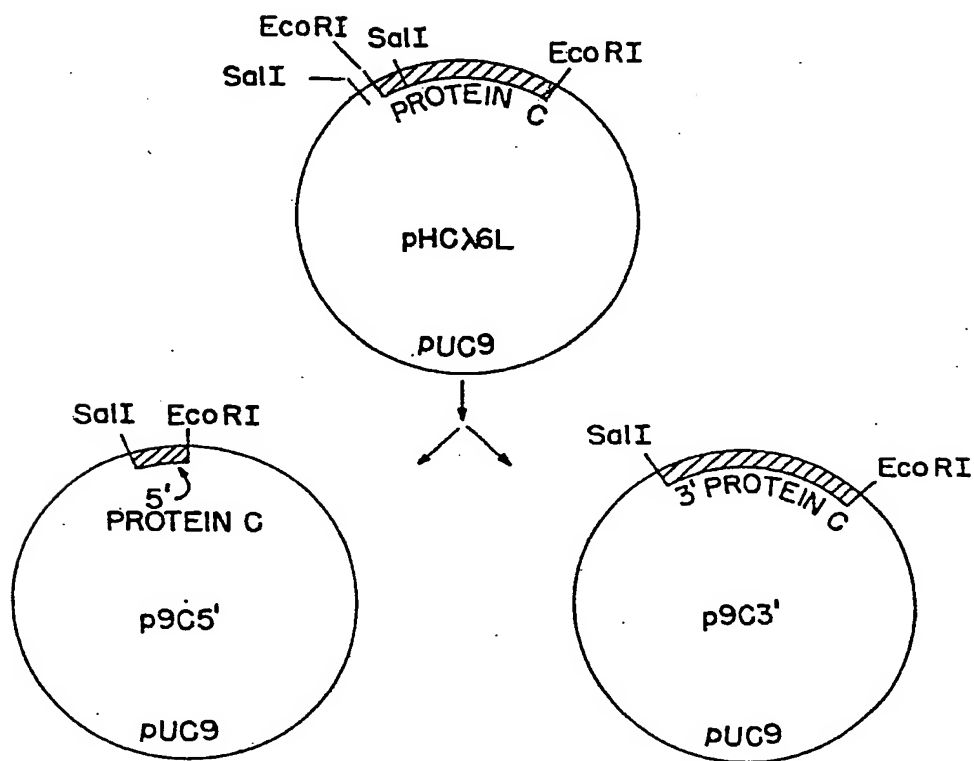


FIG. 6

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GGCTGTCATG GCGGCAGGAC GCGGAACCTG CAGTATCTCC ACGACCCGCC CCTGTGCCAG TGCCTCCAGA 0266190

-42 -40 -30
 ATG TGG CAG CTC ACA AGC CTC CTG CTG TTC GTG GCC ACC TGG GGA ATT TCC GGC
 MET Trp Gln Leu Thr Ser Leu Leu Leu Phe Val Ala Thr Trp Gly Ile Ser Gly

-20 -10
 ACA CCA GCT CCT CTT GAC TCA GTG TTC TCC AGC AGC GAG CGT GCC CAC CAG GTG
 Thr Pro Ala Pro Leu Asp Ser Val Phe Ser Ser Ser Glu Arg Ala His Gln Val

-1 +1 10
 CTG CGG ATC CGC AAA CGT GCC AAC TCC TTC CTG GAG GAG CTC CGT CAC AGC AGC
 Leu Arg Ile Arg Lys Arg Ala Asn Ser Phe Leu Glu Glu Leu Arg His Ser Ser

20 30
 CTG GAG CGG GAG TGC ATA GAG GAG ATC TGT GAC TTC GAG GAG GCC AAG GAA ATT
 Leu Glu Arg Glu Cys Ile Glu Glu Ile Cys Asp Phe Glu Glu Ala Lys Glu Ile

40
 TTC CAA AAT GTG GAT GAC ACA CTG GCC TTC TGG TCC AAG CAC GTC GAC GGT GAC
 Phe Gln Asn Val Asp Asp Thr Leu Ala Phe Trp Ser Lys His Val Asp Gly Asp

50 60
 CAG TGC TTG GTC TTG CCC TTG GAG CAC CCG TGC GCC AGC CTG TGC TGC GGG CAC
 Gln Cys Leu Val Leu Pro Leu Glu His Pro Cys Ala Ser Leu Cys Cys Gly His

70 80
 GGC ACG TGC ATC GAC GGC ATC GGC AGC TTC AGC TGC GAC TGC CGC AGC GGC TGG
 Gly Thr Cys Ile Asp Gly Ile Gly Ser Phe Ser Cys Asp Cys Arg Ser Gly Trp

90 100
 GAG GGC CGC TTC TGC CAG CGC GAG GTG AGC TTC CTC AAT TGC TCG CTG GAC AAC
 Glu Gly Arg Phe Cys Gln Arg Glu Val Ser Phe Leu Asn Cys Ser Leu Asp Asn

110 120
 GGC GGC TGC ACG CAT TAC TGC CTA GAG GAG GTG GGC TGG CGG CGC TGT AGC TGT
 Gly Gly Cys Thr His Tyr Cys Leu Glu Glu Val Gly Trp Arg Arg Cys Ser Cys

130
 GCG CCT GGC TAC AAG CTG GGG GAC GAC CTC CTG CAG TGT CAC CCC GCA GTG AAG
 Ala Pro Gly Tyr Lys Leu Gly Asp Asp Leu Leu Gln Cys His Pro Ala Val Lys

140 150
 TTC CCT TGT GGG AGG CCC TGG AAG CGG ATG GAG AAG AAG CGC AGT CAC CTG AAA
 Phe Pro Cys Gly Arg Pro Trp Lys Arg Met Glu Lys Lys Arg Ser His Leu Lys

160 170
 CGA GAC ACA GAA GAC CAA GAA GAC CAA GTA GAT CCG CGG CTC ATT GAT GGG AAG
 Arg Asp Thr Glu Asp Gln Glu Asp Gln Val Asp Pro Arg Leu Ile Asp Gly Lys

FIG.2

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FIG. 2 CONT.

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410	419
GAC AAG GAA GCC CCC CAG AAG AGC TGG GCA CCT TAG CGACCCCTCCC TGCAGGGCTG	
Asp Lys Glu Ala Pro Gln Lys Ser Trp Ala Pro	
GGCTTTTGCA TGGCAATGGA TGGGACATTA AAGGGACATG TAACAAGCAC ACCGGCCTGC TGTTCTGTCC	
TTCCATCCCT CTTTGGGCT CTTCTGGAGG GAAGTAACAT TTAGTGAGCA CCTGTTGTAT GTCACATGCC	
TTATGAATAG AATCTTAACT CCTAGAGCAA CTCTGTGGGG TGGGGAGGAG CAGATCCAAG TTTTGCGGGG	
TCTAAAGCTG TGTGTGTTGA GGGGGATACT CTGTTTATGA AAAAGAATAA AAAACACAAC CACGAAAAAA	

FIG. 2 CONT.

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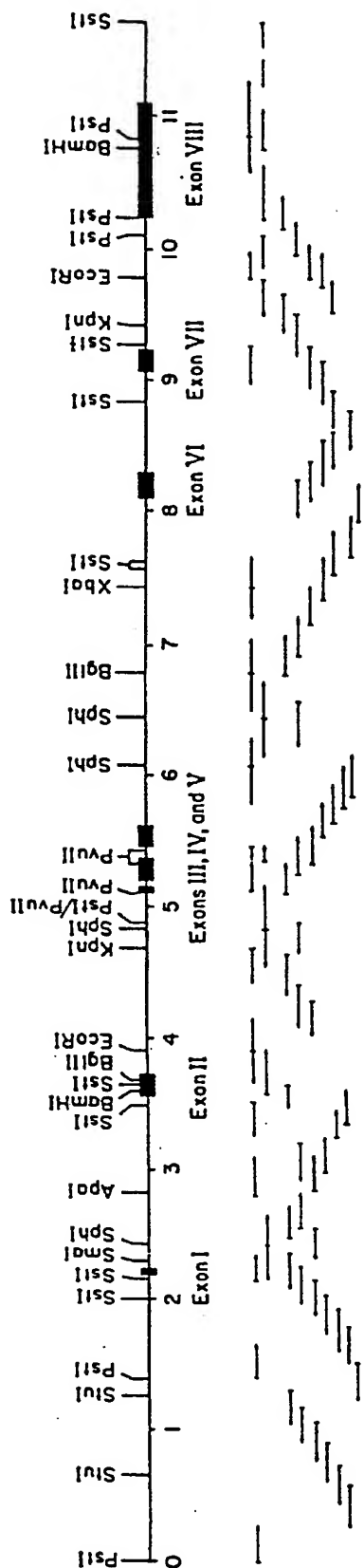


FIG. 3

AGTGAATCTG	GCGGAGTAAC	ACAAAACATTG	AGGTGCTCTTA	CCTGAANAAT	AGAGGTTTAGA	GGATGCTCTAT	GTGCCATTGT	GTGTGTGTGT	TGGGGGTGGG	GATTGGGGGT	GATTTGTGAG	CAATTGGAGG	-2001
TGAGGGTGGG	GCCCAAGTGC	GCACACCAT	GCATCTGGGA	CCCAAAAGG	AGCAATCTTCT	CATGATTTTA	TGTAICAGAA	ATTGGATGG	CATGTCATG	GCACAGCGTC	TTTTTCTTGT	TATGTTGGCA	-1871
CATAAATAT	TGTGCTTAT	AAATATGGT	ATTATAGAT	TGACAAATTA	CTGTGTGTGC	TGATCTTGGG	GCACATATAA	TATCTCTGGG	CAAAAATGTC	CCCATCTCGA	AAACAGGGAC	-1741	
AGCTTCTCTC	CTCTACGAC	CAATGATGG	CTGAAATATG	GCACAAATCT	TGCGCTTGC	CTCCTCTCCT	CTTGGATGGC	ATCCTTTGTA	GCACAGAGTG	GGCCTTGGGG	AGCGGACGAC	-1611	
TGTCTGAGCT	AGGACACAGA	GTGCTAGTG	CACCTTTTGT	CTATGGAGAG	GGAGGCTCTA	GTCTCAGGGS	CAAGCAAAAT	ATTTGTGTT	ATGGATTAAT	TGGAAGTCTCA	GCTGTGTCAT	GAGCGACGAC	-1481
GGGAATCTCT	CAGTATCTCC	ACGACACGGCC	CTGTGAGTC	CTCTCCACG	AGGGGTATG	AGGGAGGGCT	CCGCCCGGGA	GAAGAGAGCT	AGGTTGGTAT	GAGGGCTGAA	TCTCTCAGCC	-1351	
AGGGTGTCTCA	ACAGAGCTGA	CTGTGGGTA	AAAGGACACA	AGGCCCTTCA	CAGGCGCTCA	CTGCGACCA	CAGCTCTCAGG	TCCCTTTGCC	ATGGCCCTCC	CTCTTCCAG	GCCAAGAGTG	CCGAGGCCCA	-1221
GGGCATCTCC	ACAGACAGAT	TGAGAGCCCA	GGACCTCTCA	TTCTCCCAAC	CCCACTTCCA	CTTTTGGGG	TGCTGGAGTT	GAACAATCT	CAGAAGAGGC	CTCAGAGGGA	ATGTGAGGCA	-1091	
GGGTCGCGTA	GGGTTCTGAG	AGGCGACGTG	GCCTATCTCAC	TGGGAGGGT	TCCTTGATCT	CTGGCCACCA	GGCATATGTC	TGTGGCCTTT	TGGAGCAACC	TGGTGGTTTG	GGGCAAGGGT	TGAATTTCCA	-961
GGCTTAAACG	ACACAGAGCC	TGGCTTTGAG	TCCTGGCTCT	CGGAGTAATG	CATGGATATG	ACAACTGGAA	CCAGAGCAT	TGCTTCAGTC	TTCGCGATC	GGTCTGTGCA	GTGTACTGAT	GGTGTGAGAC	-831
CCCTCTATGA	AATGGGGTGT	ACACACTTAA	TAACTACTCT	TGGGTTGGTT	GTGAGCTCTA	TAATATCTCA	TGTTTACTGA	GCATGAGCTA	TGTGCAAAAG	CTGTTTTGAG	ATGCTTTATG	CTCAGTTTCC	-701
GGACTGAATC	CTTTAATTCT	TTAAGGACC	CGATACACCA	CGATTTCCA	CGATTTTAC	AATGAGAGAA	ACTGAGGACAT	GGAGCAGTGA	AGCATCTTGC	CCMACACTTG	CTCTCAGTAA	-441	
CTGTCTGAGG	AAATATTTGC	ACCGTGCAT	CTGGCTTCACT	GGCCTGCCCT	GTGAATCTGT	TTGAANAATT	CTGAACAGCA	CCATGAGTGT	TTAGCAATCG	TTAGCTAATA	TCTTCAGGCC	ACTCATCAGA	-311
CCGGGACAGG	CAGCCACCCC	ACTGTCCCCA	GGGAGGACAC	AAACATCTCT	GCACCTCTCTC	CACCTGCATTC	TGAGCTGCT	TCTTAGGCAG	CCAGTGTGAG	CTCAGGCCCA	CTTAGAGCGG	GGTCCAGG	-181
CTCTCTAGG	CTATGTCTCT	AGCGACAAAG	GACCTTCAAT	TTCAGCTTCC	GGCTGACGGC	CAGCACACAG	GGACAGCCCT	TTCAATTCCG	TTCACACTGG	GGGTCGAGGC	AGAGCACGAC	CGGGGGTAGC	-51

Met Trp Gln Leu Thr Ser Leu Leu Leu Phe Val Ala Thr Trp Gly Ile Ser Gly Thr Pro Ala
ACTGCCGGG GCTCAGAGT CCTCTCAGA CAGGTGCAG TGCCTCAGA ATG TGG CAG CTC ACA AGC CTC CTG CTG TTC GTG GCC ACC TGG GGA ATT TCC GGC ACA CCA GCT

Pro Leu
CTT CTT G Y GTAAGGCAAC CCCACCCCTA CCCGGGACCC CTTGTGGCAT CTAAAGGCC CTGGTGGCAT CTGCCAGGC CTTACAGCT TCCACCATCT CTCTGAGCCC TGGGTGGAGT GAGGGGCAGA 190

320 TGGGAATGGC AGGAATCAAC TGACAAGTCC CAGTAGGCC AGCTGGCACA GTCCACACA GGGGCTGCCA GGGCAGGCAT GCGTATGACG GCGATGACCT CCTAAGCTC CTTCTCTCAC

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840 TGTGCTCG AACACAGCAG ACAGCTTCA CACACTCAG GACCTTCTT GGGTAGAGG TGTGCTATC TCCCTGCTTG CCGTGCCAA GGGGAGGAGC ATGGGGAATA

970 TGGCTGCTGGTGGG AAGACTGGGG GGAATGTGCA AGATGGGGCT CATGTTGGTG ACAGTGAAG GATTAACTT GGCACCTTT CACAGGGCTTG AGTACTTATC

1100 TCTTTTACIA TGACGGTCTC ATCCCATGT TTTTGGATGA GTAATTTGAA CTTTAAAGG GTATTACAG TGGCTAAGG TCACACAGAG TGCTGGGTGG GGTTCACGG

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AGACCTTCCG AGGCTCTCCG AGCTGTGCTT CCTCAGACCC CTCATG6CC CCAGCCCCCT TTAG6CCCT CACCAAG6TG AGCTCCCTC CTCCTAAAC CAG⁻¹ AC TCA GTG TTC TCC AGC AGC⁻¹ Ser Val Phe Ser Ser Ser Ser⁻¹⁹

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Phe Glu Glu Ala Lys Glu Ile Phe Gln Asn Val Asp Asp Thr
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 Val Ser Trp Gly Glu Gly Cys Gly Leu His Asn Tyr Gly Val Tyr Thr Lys Val Ser Arg Tyr Leu Asp Trp Ile His Gly His Ile Arg Asp Lys Glu Ala
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 Pro Gln Lys Ser Trp Ala Pro STOP
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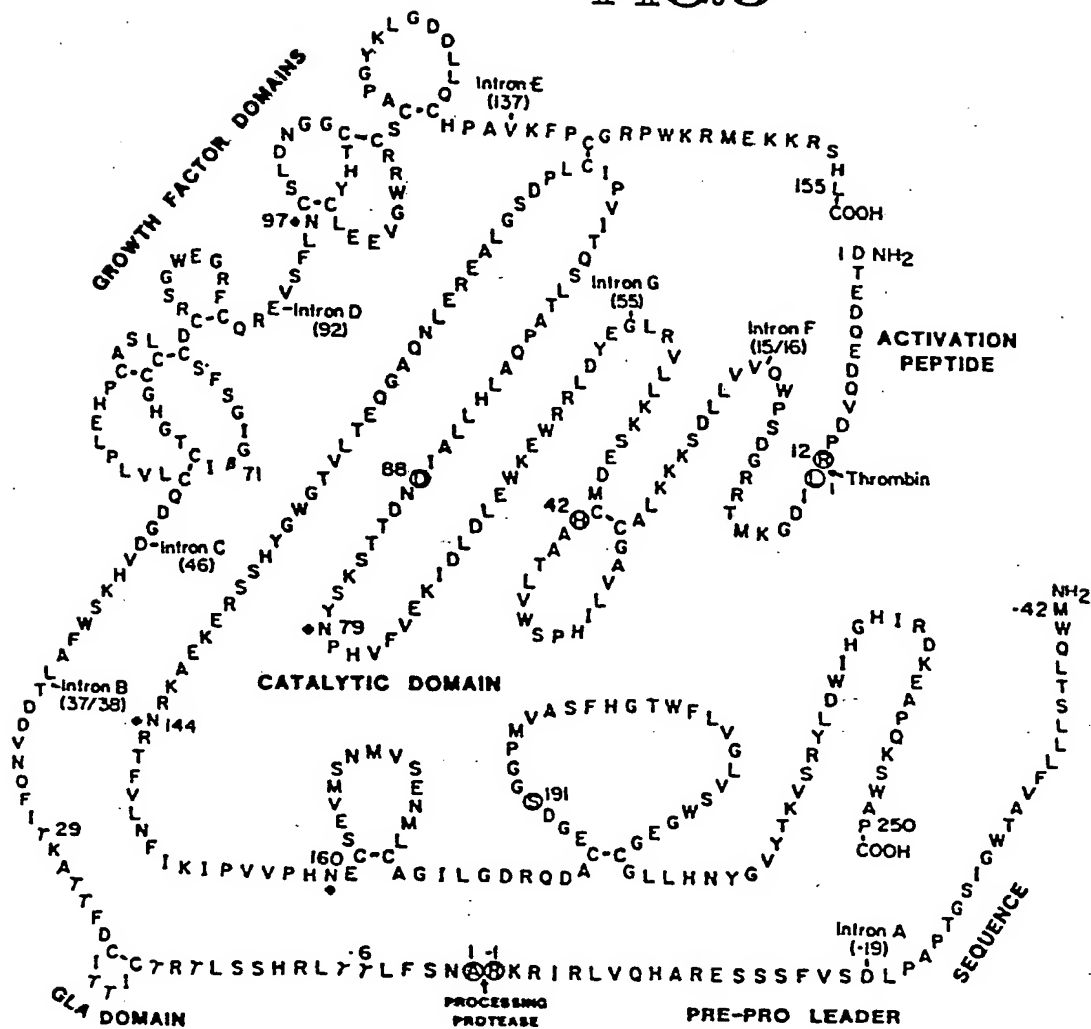
FIG. 4 CONT

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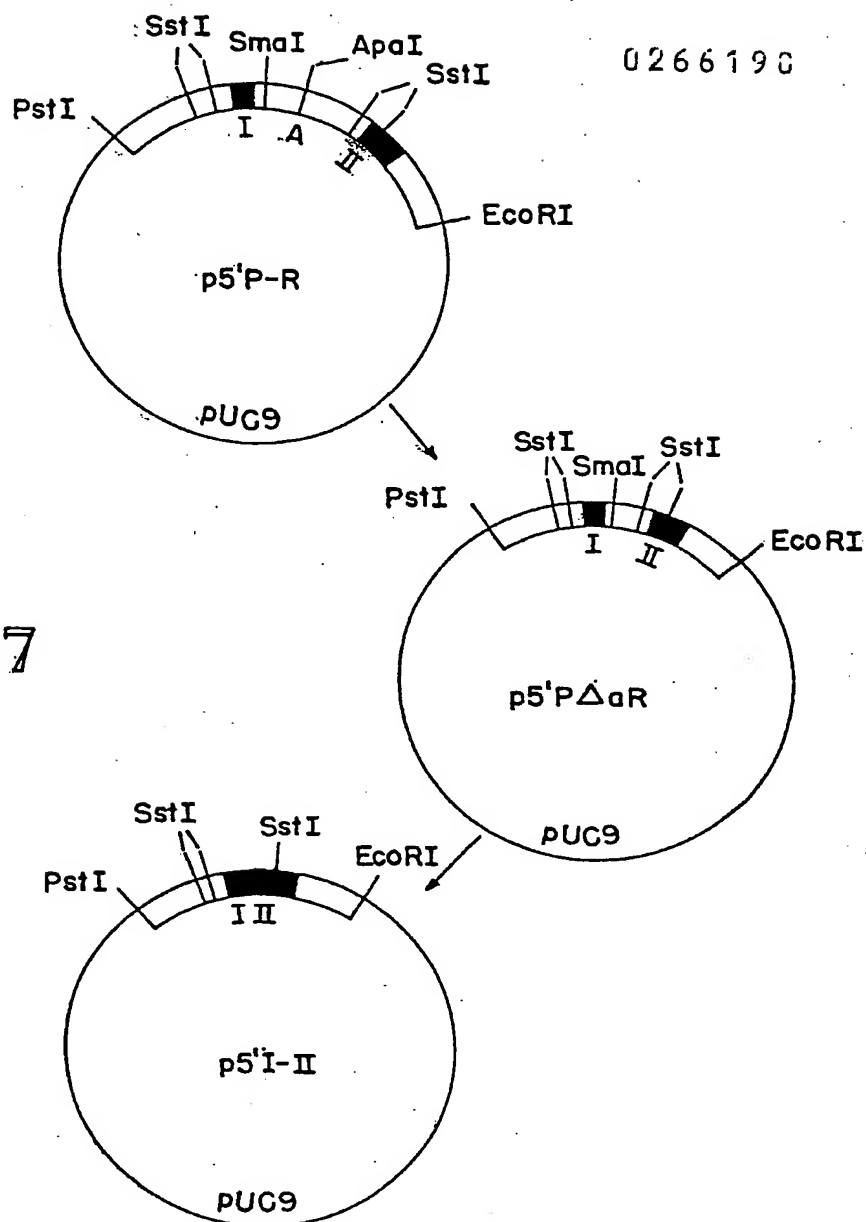
FIG. 5



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FIG. 7



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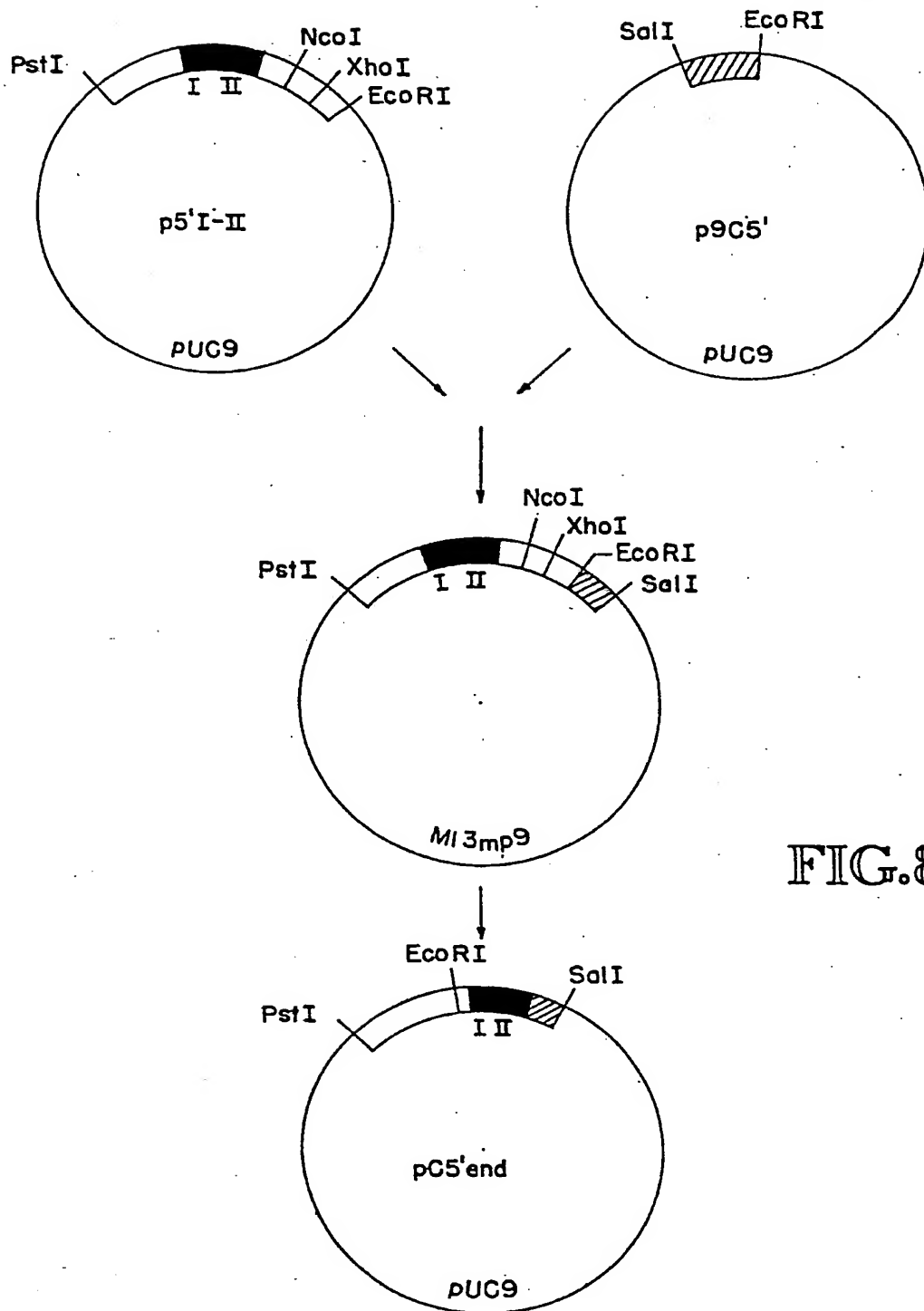


FIG.8

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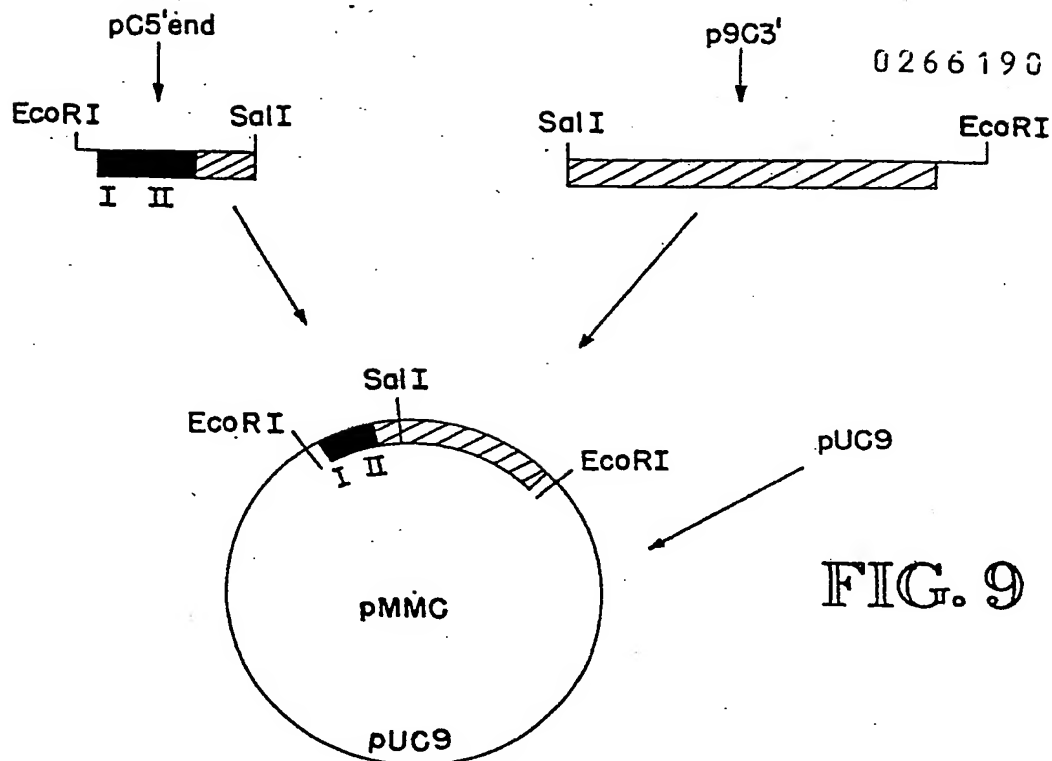


FIG. 9

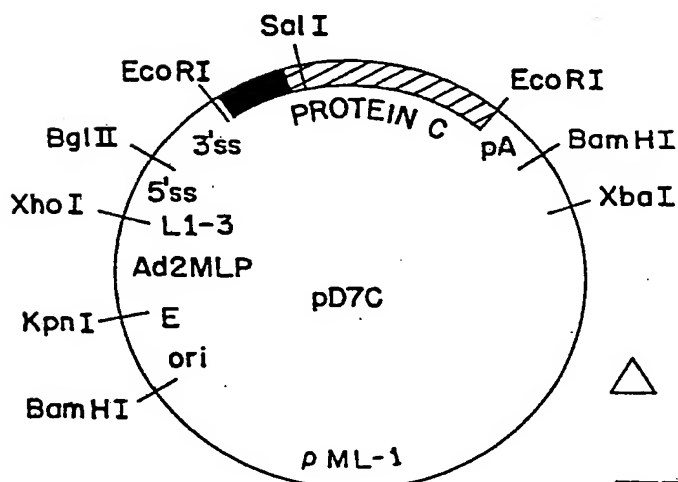


FIG. 10

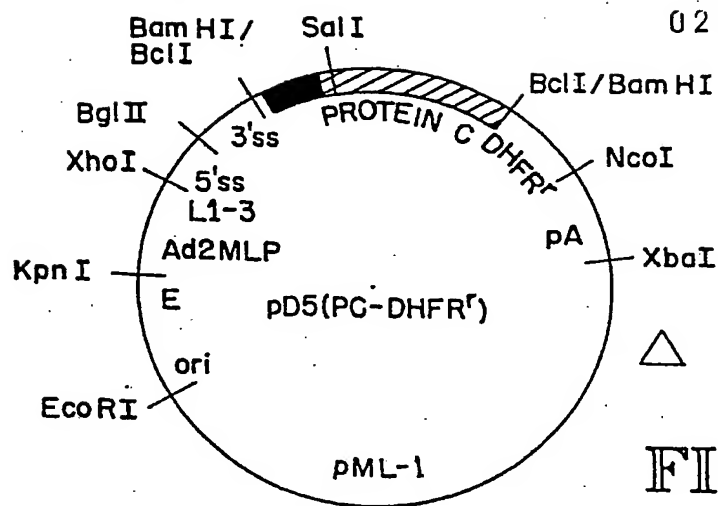


FIG. 11

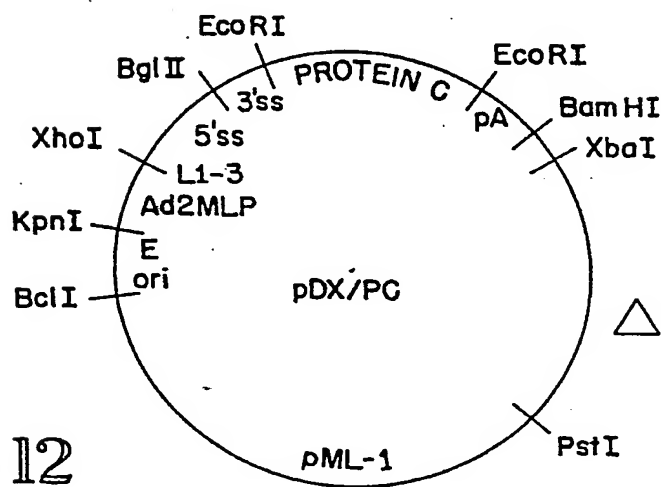
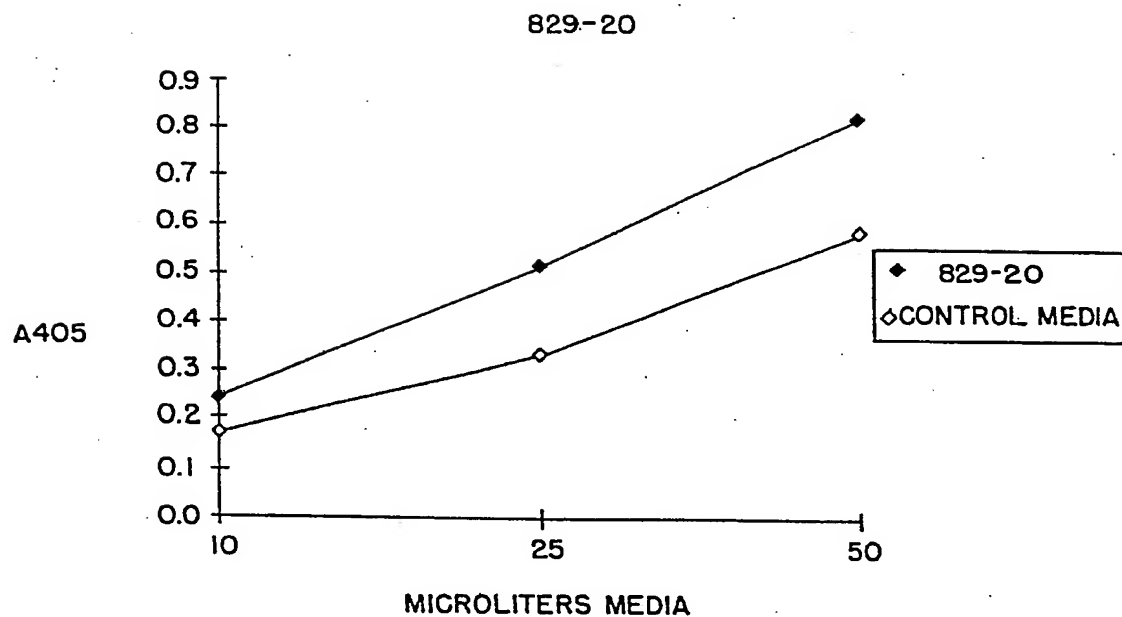


FIG. 12

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FIG. 13



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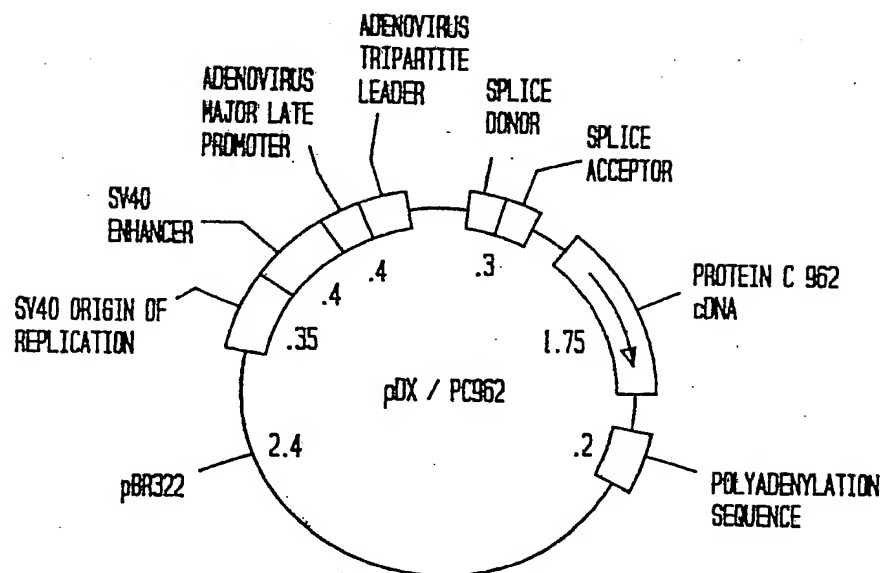
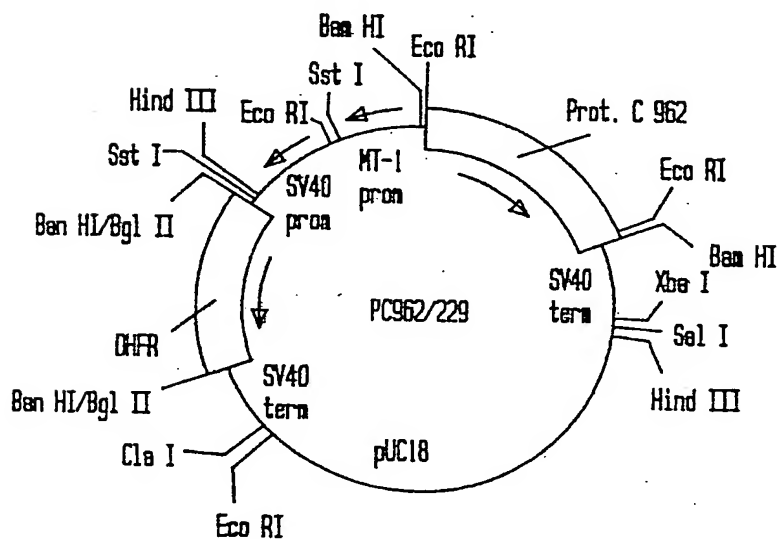


FIG.14



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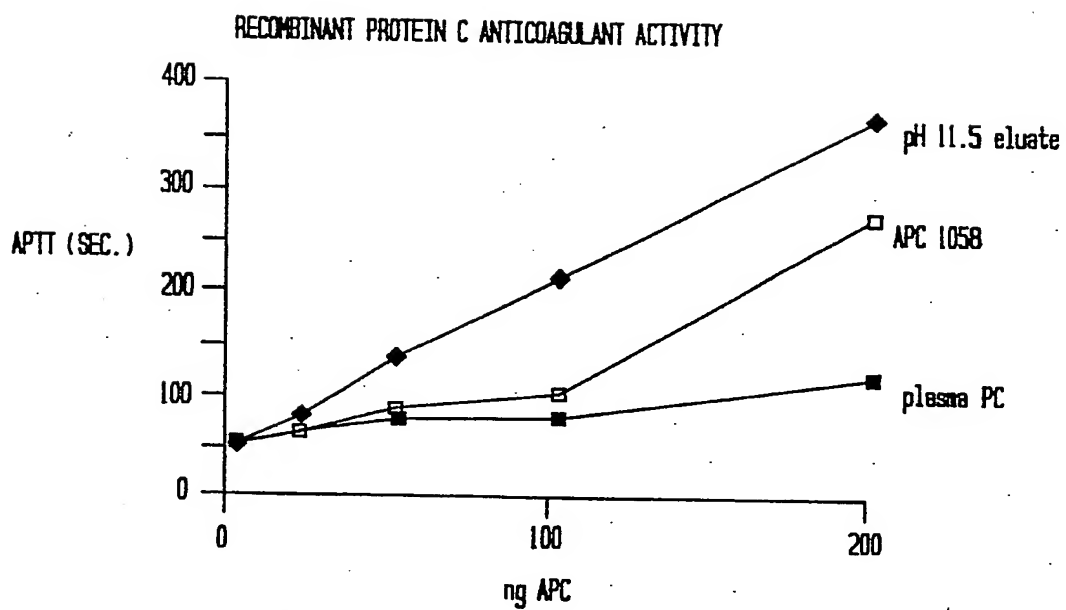


FIG.15

(19)



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(11) Publication number:

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A3**

(12)

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(21) Application number: 87309528.5

(51) Int. Cl.4: **C12N 15/00 , C12N 9/64 ,
C12N 5/00**

(22) Date of filing: 28.10.87

(30) Priority: 29.10.86 US 924462

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AT BE CH DE FR GB IT LI LU NL SE(88) Date of deferred publication of the search report:
25.10.89 Bulletin 89/43(71) Applicant: ZymoGenetics Inc.
2121 North 35th Street
Seattle Washington 98103(US)(72) Inventor: Foster, Donald C.
4908 N.E. 97th
Seattle Washington 98115(US)
Inventor: Murray, Mark J.
2211- 11th Avenue East
Seattle Washington 98102(US)
Inventor: Berkner, Kathleen L.
3032-22nd Avenue West
Seattle Washington 98199(US)(74) Representative: Brown, John David et al
FORRESTER & BOEHMERT
Widenmayerstrasse 4/I
D-8000 München 22(DE)

(54) Expression of protein C.

(57) Genomic and cDNA sequences coding for a protein having substantially the same biological activity as human protein C and recombinant expression vectors comprising these sequences are disclosed. Methods are disclosed for producing a protein which has substantially the same biological activity as human protein C. The protein, which may be in the form of activated protein C, is produced by mammalian host cells transfected with a plasmid capable of integration in mammalian host cell DNA. The plasmid includes a promoter followed downstream by a DNA sequence which encodes a protein having substantially the same structure and/or activity as human protein C, the nucleotide sequence being followed downstream by a polyadenylation signal.

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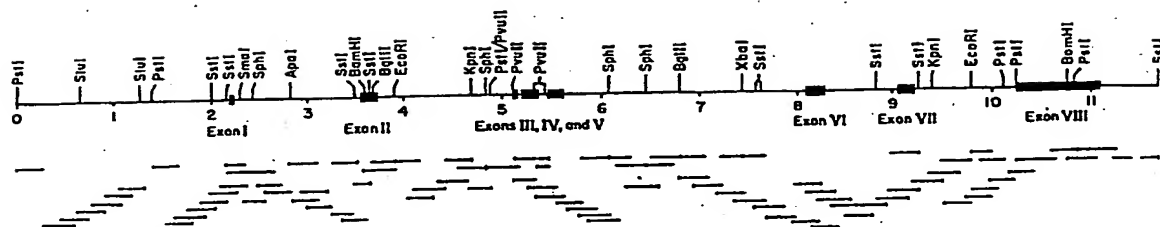


FIG.3



European Patent
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EUROPEAN SEARCH REPORT

Application Number

EP 87 30 9528

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
Y	EP-A-0 191 606 (ELI LILLY AND COMPANY) * whole document *	1-15	C 12 N 15/00 C 12 N 9/64 C 12 N 5/00
Y	PROC. NATIONAL ACADEMY SCIENCES vol. 82, no. 11, June 1985, pages 3591-3595, Washington, USA; M. R. FUNG et al.: "Characterization of an almost full-length cDNA coding for human blood coagulation factor X" * page 3592, column 2, last paragraph - page 3593, column 1; figure 2 *	1-15	
A	BIOCHEMISTRY vol. 25, no. 18, September 1986, pages 5098-5102, Washington, DC, USA; S. P. LEYTUS et al.: "Gene for Human Factor X: A Blood Coagulation Factor Whose Gene Organization Is Essentially Identical with That of Factor IX and Protein C" * abstract; figures 1,2 *	1-15	
P,A	EP-A-0 199 574 (GENENTECH INC.) * abstract; page 2, line 17 - page 3, line 31; page 5, lines 6-31; page 6, line 34 - page 7, line 4 *	1	TECHNICAL FIELDS SEARCHED (Int. Cl. 4) C 12 N 15/00 C 12 P 21/00 C 12 N 9/64
P,X	EP-A-0 215 548 (ZYMOGENETICS INC.) * page 1, lines 15-19; page 9, line 32 - page 10, line 35; page 12, line 22 - page 13, line 36; page 14, lines 1-10; claims *	3	
P,A	--- -/-	1,2,4- 15	
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 24-07-1989	Examiner JULIA P.
CATEGORY OF CITED DOCUMENTS X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document T: theory or principle underlying the invention E: earlier patent document, but published on, or after the filing date D: document cited in the application L: document cited for other reasons &: member of the same patent family, corresponding document			



European Patent
Office

EUROPEAN SEARCH REPORT

Page 2

Application Number

EP 87 30 9528

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
D, A	PROC. NATIONAL ACADEMY SCIENCES vol. 81, August 1984, pages 4766-4770, Washington, USA; D. FOSTER et al.: "Characterization of a cDNA coding for human protein C" * page 4767; figure 2 *	1-15	
A	PROC. NATIONAL ACADEMY SCIENCES vol. 82, July 1985, pages 4673-4677, Washington, USA; D. C. FOSTER et al.: "The nucleotide sequence of the gene for human protein C" * whole document *	1-15	
			TECHNICAL FIELDS SEARCHED (Int. Cl.4)
The present search report has been drawn up for all claims			
Place of search BERLIN		Date of completion of the search 24-07-1989	Examiner JULIA P.
CATEGORY OF CITED DOCUMENTS			
X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	